DEVELOPMENT OF AN INTEGRATED DECISION-MAKING MODEL FOR THE SUSTAINABLE MANAGEMENT OF COMMUNITY BUILDINGS IN AUSTRALIA

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DECLARATION

I certify that, except where due acknowledgment has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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ABSTRACT

Infrastructure owned by local government such as roads, bridges, community buildings etc. represents an investment which has been built up over generations. Community buildings such as childcare centres, aged care centres, and sports pavilions, with a total value of over 15 billion Australian dollars in 2006, are the second largest infrastructure asset in Australia in terms of capital value. Community buildings play a key role in providing essential services to the community. Hence, their sustainable management is vital to local councils, but the delivery of those services has been limited by the ongoing degradation of the structural and service components of buildings, the scarcity of resources and the lack of funding by state and federal governments. Sustainable management is heavily dependent on, and implemented through, councils' decision-making structures. This study explores the sustainability practice of community buildings in broad, not only leaned to the parameters of the environmental aspect, through a detailed study of current practice and an extensive literature review of the sustainable management of buildings.

The sustainable management of community buildings has been considered from four viewpoints: environmental, economic, social and functional. It was then combined with influencing factors of each aspect. Two industry-wide questionnaire surveys were conducted to identify the key influencing factors and their relative importance. The research pinpointed 18 criteria to represent four sustainability aspects following the application of "Factor analysis" technique to the given responses of the first questionnaire. The findings led to the development of a three-level hierarchical decision-making structure and later to the production of a decision-making model. The model followed in two methods analytically; the evaluation technique of one of two methods was solely based on Analytical Hierarchical Process (AHP). The other evaluation technique was a combination of AHP and Neuro Fuzzy System.

The output of the model computes the sustainability index which interprets the total sustainability impact caused by a given building component. Hence, building asset managers can use the sustainability index to prioritize the

maintenance tasks of building components. The study also focuses on the cost-optimization of maintenance activities, considering on-going deterioration and the performance to be maintained during the planned period. Lastly, the research determines the best intervention times for the renewal of whole building assets during the planned period.

The study presented here was conducted as part of an Australian Research Council (ARC) linkage project which is research collaboration among RMIT University and six Victorian local councils. The outcomes of the project will enable building asset managers to optimise their decision-making on planned maintenance, rehabilitation and capital expenditure on the basis of a realistic understanding of the building deterioration. The outcomes are delivered through a user-friendly web-based software tool with comprehensive and flexible asset management data-base capabilities. The national benefit includes the significant improvement of service delivery in terms of demand, social aspects, user comfort, risk mitigation and sustainability arising from the better design and management of community buildings.

KEY WORDS

Community buildings, Sustainable management, Decision-making structure, Decision-making model, Analytical hierarchical process (AHP), Neuro-Fuzzy system, Cost-optimization of maintenance activities, Best interventions for renewals

LIST OF PUBLICATIONS

Peer reviewed conference papers:

- **Pushpitha Kalutara**, Guomin Zhang, Sujeeva Setunge and Ronald Wakefield (2013), "Sustainable management of Australian community buildings: An integrated decision-making framework", Proceedings of ICOMS Asset Management Conference, Melbourne, Australia, June 3-6, 2013 **(Best paper award recipient under the post-graduate research category)**

- **Pushpitha Kalutara**, Guomin Zhang, Sujeeva Setunge and Ronald Wakefield (2012), "Factor analysis in establishing a decision-making framework for the sustainable management of community buildings in Australia", Proceedings of the ISBEIA 2012, Bandung, Indonesia, September 23-26, 2012

- **Pushpitha Kalutara**, Guomin Zhang, Sujeeva Setunge, Ronald Wakefield and Hessam Mohseni (2011), "Decision-making for the Sustainable Management of Community Buildings in Australia using Fuzzy Logic", Proceedings of the CRIOCM 2011, Chongqing, China, September 23-25, 2011

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TERMINOLOGY AND ABBREVIATIONS

BEA- Building Environmental Assessments

LCA- Life Cycle Assessments

GBC- Green Building Challenge

SBE- Sustainable Built Environment

BREEAM- Building Research Establishment Environmental Assessment Method

LEED- Leadership in Energy and Environmental Design

CASBEE- Comprehensive Assessment System for Building Environmental Efficiency

ENVEST- ENVironmental impact ESTimating design software

RSLC- Reference Service Life of the Component

ESLC- Estimated Service Life of the Component

LCC-Life Cycle Cost

NAMS- National Asset Management Strategy Group

CAMS- Council Asset Management System

AHP- Analytical Hierarchical Process

AI- Artificial Intelligence

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Although the present research is reported under my name, several people contributed to its outcomes, either directly or indirectly. Without their support and guidance, I would not have reached the position where I currently stand. Hence, it is my duty to thank and acknowledge all of them and share all the credit with them.

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1 INTRODUCTION

1.1 Background

The term “sustainability” was unknown until the 1960s (Keeler and Burke, 2009) and we have subjected ourselves and following generations to environmental degradation, pollution and health hazards (Sendzik et al., 1997, Keeler and Burke, 2009). This has become a global issue, which has compelled people to consider sustainable development, which is defined as “meeting the needs of the present without compromising the ability of future generations to meet theirs” (Brundtland, 1987). The term applies to completely new buildings and also to managing existing buildings. The sustainable management of infrastructure is essential and the sustainable management of community buildings, one specific part of the infrastructure, is the focus of this thesis.

The global importance of and need for sustainable socio-economic development demands for an informed decision-making process for the built-environment (McDulling, 2006). Past research studies have focussed on two important aspects of informed decision-making from the perspective of the built environment. The first is to predict the optimum service life and life cycle costs of infrastructure depending on the deterioration predicted over time (Bamforth, 2003, Mohseni et al., 2012b, Kirkham et al., 2004). The second is to assess the impact of sustainability during the operation of the building or when it is designed (Sommerville et al., 1996, Jönsson, 2000, Boonstra and Pettersen, 2003, Sinou and Kyvelou, 2006, Weerasinghe and Ruwanpura, 2009). The first aspect leads to an optimal investment in infrastructure assets by ensuring that they are appropriately maintained, renewed, replaced, enhanced or disposed of so as to provide the required levels of service now and into the future at the minimal life cycle cost (Champion, 2009). Similarly, the second aspect attempts to reshape the design process in terms of the efficient management of environment, economy and society (Sinou and Kyvelou, 2006).

Community buildings in Australia, such as aged care centres, childcare centres, community centres, sports pavilions, serve local communities by providing diverse services. They evolve over generations; therefore, a large financial investment has been accumulated by the country's economy over time. Consequently, they have become the second largest asset class of infrastructure assets and their financial value is equivalent to around 25% of the total value of all infrastructure assets (Edirisinghe et al., 2012). In addition, building management, in particular the renewal, refurbishment and intervention features, has been challenging for two major reasons. The first is that the high level of complexity of buildings compared to other asset classes. The limitations of specific and comprehensive asset management models for buildings compared to other asset classes are the second reason. Hence, local government agencies urgently need to derive reliable strategic plans for the sustainable renewal of the maturing community building stock.

RMIT University initiated an industrial collaborative research project with the view of developing a reliable asset management model for community buildings. The industry collaborators include six Victorian local councils together with the Municipal Association of Victoria (MAV) and a software development company (Integrated Australia Pte Ltd). The research had two focuses according to the anticipated goals. The first was to monitor the current condition data of the partner councils and attempt to discover ways of predicting building deterioration. The second was to research the sustainable management of community buildings and attempt to develop a decision-making model. The latter is the main focus of the present thesis, whereas the former was the responsibility of another researcher attached to the same industrial project. Some content of the other study will be referenced appropriately within the present work, to maintain the content flow.

1.2 Research significance

Whilst there are a large number of studies for the life cycle assessment of buildings, studies for the sustainable management of existing buildings have been fewer in number. In those few studies, existing commercial buildings have been the most studied. As community buildings are a type of commercial building, the findings of previous studies can be correlated with community buildings with respect to sustainable management. For example, Watson et al. (2004) reported that sustainable building design involves the consideration of stakeholder relationships while addressing an array of environmental, social and economic criteria. On the other hand, Sarja (2002) argued that the sustainable design of structures should include not only those three impact aspects but also functional aspects. Having tailored these ideas to community buildings and consulted experts in the area of community buildings (six partner councils) for their opinions, the current research suggests the consideration of these four aspects for the sustainable management of community buildings in Australia.

In the research literature, several studies identify factors affecting certain sustainability aspects, particularly factors related to environmental issues. For example, Boonstra and Patterson (2003) reviewed six different environmental assessments for existing buildings adopted by six countries; Australia (NABERS), Sweden (Environmental status), Norway (Ecoprofile), Canada (Green Globes), France (HQE) and Japan (CASBEE). A similar approach, but with attention given to socio-economic factors, was undertaken by Sinou and Kyvelou (2006) in their study of the comparative analysis of various building performance assessment tools. However, in contrast to environmental factors, very few studies have concentrated on socio-economic concerns in assessments and even fewer on the functional aspect. For example, Mcshane (2006) emphasized the social value of community infrastructure, and Benoit et al. (2010) formulated guidelines for social life cycle assessments of products. Despite the availability of several assessments for buildings in current practice connected with sustainability, there is no integrated model to comprehensively assess sustainability from all four aspects i.e. environmental, social, economic and functional (Sinou and Kyvelou, 2006).

Current decision-making models for buildings are basically relying on life cycle assessments (LCA), regardless of the building type or the status of the building, whether in operation or design. These LCA tools are used to calculate the sustainability impact of the building (Keeler and Burke, 2009). In addition, a considerable number of software tools have been developed for decision- making on building retrofits. In most cases, radar graphs are used to summarise the deterioration of the building elements. EPIQR (Flourentzos et al., 2000b), MEDIC (Flourentzou et al., 2000), TOBUS (Caccavelli and Gugerli, 2002), Office Scorer (Sidewell et al., 2004), and MAR (Sidewell et al., 2004) are widely-used software models for decision-making on building retrofitting. CONFIRM, Moloneys, Drawbridge, Conquest, Logometrix, My predictor are other commonly used software tools in the current practice of local council agencies. In order to address the gaps in knowledge and deal with the current practice, the present research address the following issues:

- No assessment in the existing research literature covers a wide range of aspects in terms of sustainability, apart from environmental assessments.
- No building asset management model in the current practice uses a holistic system to make decisions on the sustainable management of community buildings.
- Informed decisions on the management of community buildings require prioritising of building components for their maintenance activities.
- Allocation of budgets for maintenance activities requires a cost-optimisation approach.
- A method is required for determining the optimum intervention time for the renewal of whole building assets.

1.3 Research questions

Considering the background of the research, the broad question was:

How can community buildings be managed in a sustainable way?

In order to provide clarity to the broad question, four sub-questions were developed:

i. What are the current practices applied by partner councils for the management of community buildings?

The awareness of existing systems for the management of community buildings is essential prior to considering the problems. As the project is a collaborative one with six local councils, this task was considerably easy. The answers enabled the researcher to understand the flaws, and the good features, and gain an understanding of important aspects in connection with the sustainable management of community buildings.

ii. How can the sustainable management of community buildings be measured?

Sustainable development is defined as “meeting the needs of the present without compromising the ability of future generations to meet theirs” (Brundtland, 1987). Alternatively, sustainability is interpreted as continuing something over a long period (Cambridge advanced learner's dictionary, 2005). In accordance with both ideas, sustainability can be seen as a comparison of a future state with a standard state of the present or the past. Moreover, sustainability measurements at a future state can be calculated by comparing the sustainability measurements of the present or a past state. The overall picture of the sustainable management of community buildings coincides with their sustainability aspects. Further assessment of the influencing factors of each aspect will provide a comprehensive answer to this research question.

iii. How can the different aspects of sustainable management be integrated to develop a decision-making model for prioritizing maintenance activities?

Decision-making is the foundation of any management system. It requires a robust decision-making structure for making comprehensive decisions. Hence, a robust decision-making structure is developed well directed to the sustainable management of community buildings through the results to Question ii. The evaluation process calculates the final outcome through the parameters appearing in the derived decision-making structure. The problem becomes more challenging and time-consuming because community buildings include a large number of building components and every local council has a large number of community buildings under their management. Hence, having a model is essential to address this issue. It is also necessary to research possible analytical methods for an effective evaluation. Finally, building components can be prioritised depending on the results captured by the model.

iv. How can the maintenance cost be optimised, taking into account ongoing deterioration and the requirement for performance to be maintained?

To answer this question, an explorative approach is required to understand the variation of the maintenance cost at different performance levels with ongoing deterioration.

v. How can optimum intervention times be determined for the renewal of whole building assets during a planned period?

The answer to this question depends on the deterioration curve of the whole building asset. The time of the intervention depends on the parameters of the deterioration curve.

1.4 Research objectives

The specific objectives derived from the research questions are as follows;

i. Development of a comprehensive decision-making structure to measure the sustainable management of community buildings

ii. Development of a decision-making model (sustainability index) for the sustainable management of community buildings

iii. Prioritization of building components for maintenance activities using the sustainability index model

iv. Development of a program to optimize the maintenance cost

v. Development of a method to determine optimum intervention times for renewal of whole building assets

1.5 Scope of the thesis

The following areas are covered in the present thesis;

i. Identification of sustainability aspects and the related sustainability factors in the context of the management of community buildings

ii. Use of the factor analysis technique to create smaller groups out of an expanded list of factors and the development of the final decision-making structure

iii. Use of the multi-attribute decision-making approach for the development of the decision-making model

iv. Use of the analytical hierarchical process (AHP) and Neuro-Fuzzy applications in the evaluation of the decision-making model

The following areas are beyond the scope of this thesis;

i. Deterioration prediction of community buildings using the Markov process based on condition data sets available from the councils associated with the present research. This matter was covered in a parallel research project which was associated with the present research through a linkage project.

1.6 Methodology

The research objectives and problems required the researcher to find a methodology to achieve the objectives and overcome the problems. Knowledge derived from the literature review and the current practice in building management systems was utilised in designing the best methodology for the research. Preliminary data collection was carried out to explore the current practices of several local councils in Victoria, Australia. Council visits following responses to a questionnaire were the modes of data collection. Seven strategic areas related to community building management were investigated during the data collection. A summary of the details is shown in Table 1.1. The results enabled a better understanding of the management strategies in current practice, and the identification of gaps in current knowledge.

Table 1.1: Management strategies of associated councils

Council	Management Strategies							
	Condition Audits	Element Hierarchy	Condition Rating Method	Data Collection Method	Deterioration Prediction	Cost Forecast	Decision Making	Other
Council A	No. Only building valuations	N/A	N/A	Visual inspection	No	Overall budgeting and Moloneys model	Considers affecting factors	Available maintenance audits and disabled condition audits
Council B	UMS* condition audits	UMS* hierarchy, Moloneys list	0-10 Moloneys	Visual inspection	No	Moloneys model and CashFlow5	Cashflow5	UMS* element hierarchy mapped to Moloneys elements
Council C	Yes, annually	Own hierarchy	1-5	Visual inspection	No	In house developed 10 year renewal program	Model in progress	
Council D	Yes	1-5condition audit manual	Own list of elements	Visual inspection	Yes	Rules in PMS	Model in progress	Building material and age are considered
Council E	Yes	Own hierarchy	1-5. Detailed condition audit manual	Visual inspection	No	Based on integrated condition rating	Committee based prioritising	Integrated condition rating
Council F	Yes	Own hierarchy	1-10	Visual inspection	No	Based on integrated condition rating	Model in progress	Integrated condition rating

***-Utility Maintenance System**

The second research question caused the study to undertake an extensive literature review of the sustainability of local government infrastructure. The major features of corporate sustainability were captured through a thorough literature review of the topic of sustainable development. They were later confirmed as applying to community buildings by the verification of partner councils. State of the art of building assessments, either rating systems or life cycle assessments, were utilised to find the relevant factors affecting each sustainability-driven aspect. They were tailored to community buildings based on the expert opinions shared by council professionals from the partner councils.

The result was a large list of factors, which raised a concern whether the list was practically adoptable when the factors were combined with the bottom level of the building hierarchy. This created a need to compress the list into a small number of groups of factors. Factor analysis, a statistical method, was useful in this purpose and it required a questionnaire to be conducted before the analysis. Hence, the first questionnaire was designed, and verified in a pilot survey among partner councils. Responses were obtained using a web-based questionnaire which was created using the web-based software “Survey monkey”. The revised questionnaire was disseminated among local councils in Australia and their responses were used first for confirmation of the derived factors and later for factor analysis. This is discussed in detail in Chapter 4.

Through the factor analysis, similar characteristic factors under each aspect were grouped and named as the criteria of each aspect. According to the building hierarchy chosen, the measurement of sustainability impact targeted the hierarchical level of “building component” with the decision-making model. Criteria which were derived from the factor analysis were identified as the starting point of the evaluation of the model. The impacts caused by the building components on four sustainable aspects were then calculated based on the results of criteria. Finally, the total sustainability impact was evaluated by integrating the impact values of four sustainable aspects.

The most suitable approach to decision-making problem here was the use of multi-attribute decision-making methods. Analytical hierarchical process (AHP) combined with simple additive weighting was one method for comprehensive solution. Looking at the variables and their input and output values, lexical uncertainty was predominant through the whole evaluation system. This phenomenon led the research to choose another appropriate method from artificial intelligence (AI) applications. The Neuro-Fuzzy approach was considered the most suitable method for part of the evaluation. A detailed discussion of both approaches is given in Chapter 6. Either method, the output of the model gives the sustainability impact of a given building component which will be utilised to prioritise maintenance activities of building components. Once this was done, research question iii was completely answered.

A program was developed to optimize the maintenance cost of previously prioritised building components. This enabled the calculation of the cost values required for each building component to be maintained in any condition without declining during the planned period. A detailed explanation of the development of the program with example calculations is shown in Section 8.3. The methodology section then covers the determination of the best intervention periods for the renewal of whole building assets, which is explained in detail in Section 8.4. The solutions to the optimization of maintenance cost and the determination of best intervention times were the answers to research question iv and v.

1.7 Organisation of the thesis

This thesis is organised as follows:

Chapter 1 describes the background to the research, followed by its significance, questions, objectives and scope. A brief description of the research methodology is also presented.

Chapter 2 presents a critical review of the literature covering all the pertinent areas of the research. They include “sustainable management of buildings”, “building assessments”, “building management models”, “generic infrastructure asset management systems”, “decision-making methods”, “analytical hierarchical process”, “artificial intelligence applications”, “condition monitoring of buildings”, “building hierarchical systems”, “deterioration prediction” and “cost evaluation techniques”.

Chapter 3 deals with the methodology adopted in this research. The methodology is explained based on the research design and the research process. The research design is outlined according to the purpose of the study, type of investigation and so on. The research process is explained including how the current practice was established, data collection methods and so on.

Chapter 4 explains how the research developed the influencing factors for decision-making in the sustainable management of community buildings. To do this, the researcher conducted an industry-wide questionnaire. The chapter gives a detail description of the data analysis and the results based on the responses to the questionnaire.

Chapter 5 continues with the factors established in the previous chapter. The aim is to acquire the significance of the factors for the sustainable management of community buildings by assigning a weighting value to each factor. The second industry-wide questionnaire was conducted for that purpose. The chapter provides the data analysis and results according to the responses obtained on that questionnaire.

Chapter 6 presents the development of the decision-making model, mainly based on the hierarchical structure for decision-making developed previously. The evaluation process deals with the weighting values previously obtained and the individual impact values which must be given as input values. The evaluation follows using two analytical methods; one is a pure application of the analytical hierarchical process (AHP), whereas the other is a combined application of the AHP and Neuro-Fuzzy systems.

Chapter 7 is dedicated for the verification, validation and demonstration of the model. The chapter follows with two case studies.

Chapter 8 proposes three informed decisions important to the sustainable management of community buildings. They are the prioritisation of maintenance activities of building components; the optimisation of cost in maintenance activities; and the determination of the best intervention times for whole building assets for renewals.

Chapter 9 presents the proposed software tool based on the outcomes of the industrial research project. The structure and framework of the program is discussed in this chapter.

Chapter 10 summarises the conclusions drawn from the research. It also states the contributions to knowledge and practice of the research. The chapter explores further research and concludes with recommendations for future research

2 LITERATURE REVIEW

2.1 Introduction

In this section, previous studies of the evolution of sustainable development and its assessment are reviewed, together with building management models which address decision-making in different forms. This is followed by a review of generic infrastructure asset management systems, in order to provide a clear picture of goals and objectives from the local council perspective. The review then considers potential decision-making methods from which appropriate techniques were selected for the present research. The analytical hierarchical process (AHP) and Artificial Intelligence (AI) systems with Fuzzy logic are explained and identified as appropriate techniques for the research. These are discussed in two separate sections.

Condition monitoring is a vital aspect of the management of infrastructure including community buildings. The condition gives an indication of the degradation of any building component, and this is the fundamental approach to decision-making. Condition monitoring is governed by an appropriate inspection system, which needs a comprehensive building and elemental hierarchical system. Section 2.8 and 2.9 cover condition monitoring and building and elemental hierarchical systems. In addition, several aspects are essential for community building management, in which deterioration prediction and cost evaluation techniques play a key role. The Markov chain has been identified as a comprehensive technique for deterioration prediction; hence it is discussed in Section 2.10. Followed with Section 2.11, covering cost evaluation- techniques, the chapter ends with concluding remarks.

2.2 Sustainable management of buildings

2.2.1 Sustainable development

Earth has undergone several upheavals over time caused by human involvement. At the beginning of civilisation, humans lived as a part of the environment with a balanced eco-system, but caused the balanced eco-system to be damaged by unconstrained population growth. The Industrial Revolution transformed the primarily agricultural society of rural-based small-scale communities into an industrial, large-scale and fast-paced society (Keeler and Burke, 2009). This caused appalling results for nature as humans exploited it causing alarming environmental effects (Daly, 1994). In addition, the scarcity of resources for the ever-growing population was a global issue due to the huge material consumption for technological applications (Ayres, 2002). These issues gave rise to the beginning of widespread public concern over environmental degradation in the developed countries of the west in the 1960s (Eckersley, 1992). These concerns have become a global phenomenon and become more advanced by amalgamating economic, social and cultural concerns with the environmental concerns for the built environment (International Council for research and Innovation in Building and Construction, 1999).

Sustainable development is defined as “development that meets the needs of the present without compromising the needs of the future generations”(Brundtland, 1987). The goal of sustainable development is to address unsustainable patterns of consumption contributing to the escalation of environmental deterioration. Other scholars have defined the term “sustainability” in different and broadening ways. Most forms of sustainability are connected to the quality of life and the capacity to maintain the environmental, economic and social arenas (Hart, 2013, Yang et al., 2008, Weerasinghe, 2012). The notion of sustainability made the three arenas the “triple bottom line” business benefits of a sustainable business (Elkington, 1997). However, those three arenas behave reciprocally (Figure 1.1). Therefore, it is important to understand their interconnected links during the process of design or operation (Hart, 2013). On the other hand, ecological sustainable development is defined as using, conserving, and enhancing community resources so that ecological processes on which life depends are maintained and the total quality of life now and in the future can be increased (Council of Australian Governments, 1992, Watson et al., 2004).

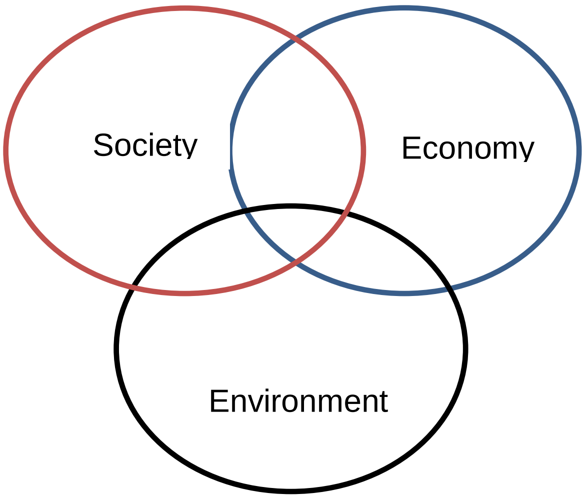


Figure 2.1: Reciprocal relationship of sustainability constituents

Source: (Hart, 2013)

2.2.2 Sustainable buildings

The built environment is a man-made creation which includes cities, infrastructures, buildings, products, landscapes and public spaces (Birkeland, 2012). Of these, buildings provide habitat for humans. Sarja (2002) explains the importance of buildings as follows:

> *Buildings, civil and industrial infrastructures are the longest lasting and most important products of our society. The economic value contained in buildings, civil and industrial infrastructures is, to say the least, significant and the safe reliable and sound economic and ecological operation of these structures is greatly needed. Buildings and civil infrastructures in industrialised countries represent 80 precent of national property. Construction plays a major role in the use of natural resources and in the development of the quality of the natural environment in our time. Consequently, building and civil engineering can make a major contribution to the sustainable development of society.*

Sustainable building has been defined by Sarja (2002) as a technology and practice which meets the multiple requirements of the people and society in an optimal way during the life cycle of the built facility. According to him, multiple requirements are captured fulfilling social aspects, economic aspects, functional aspects and ecological aspects. Following a similar idea, Weerasinghe (2012) suggests that sustainable buildings are the end result of an integrated design process of sustainability goals, decision making process and a sustainable construction process.

The current study narrows its research focus on community buildings in Australia for their sustainable practice. There are many types of buildings belonged to community buildings but not limited to aged care centres, childcare centres, community centres and halls, sports pavilions and change rooms, libraries, museums, toilets and administration buildings. Their importance to the community can be differed according to their intended services. Hence they can be again categorised as a community facility, cultural facility, sports and recreation facility, municipal facility and so on. In Australia, some community buildings, such as footy pavilions, are a big challenge for local councils to provide the minimum level of service as required by the community. Currently, most council's evaluation of the minimum level of service is mainly relied on the cost factor which the community is willing to pay for the service. However, social, environmental and functional expectations seemed to be excluded in the evaluation. These are hugely important in making decisions on the aspects of renewals, maintenance, upgrades or a complete new capital work. Hence, as the first step, four decision aspects suggested by Sarja (2002) can be adopted in the sustainable management of community buildings in Australia.

2.3 Building assessments

2.3.1 Background

> *Building facilities provide the physical space for those people working therein, the application of technology and business processes. They provide essential services for the*

> *tenants and users across a wide range of different building types* (IPWEA, 2009).

Buildings play a key role in every area of service including transportation, communication, water supply and sanitation, and activities connected with energy, commerce and industry. The importance of buildings is further increased due to the fact that buildings together with infrastructure represent more than 50% of the real capital of developed countries (Jernberg et al., 2004). On the other hand, they are responsible for a high percentage (approximately 40%) of consumption of material and energy and waste to landfill (Hovde and Moser, 2004). In relation to the Australian built environment, they are not only the cause of the depletion of natural reserves of fresh water, clean air and naturally productive land, but also the pollution of urban air to extent which is detrimental to the health of both human communities and natural ecosystems (Gilbert, 1998). The significance of buildings to humans and their inherent effects on the environment has resulted in a global push for environmental-friendly building governance. The end result has been the emergence of building assessments, in the form of building environmental assessments (BEAs).

BEAs focus on green building practices which aim to reduce the environmental impact of buildings. BEA has emerged as a legitimate means to evaluate the performance of buildings across a broad range of environmental considerations (Cole and Larsson, 1999). BEAs are in the form of rating systems which provide a scale for measuring a building's incorporation of green building strategies, compared with more conventional, mainstream buildings (Keeler and Burke, 2009). Furthermore, BEAs and life cycle assessments (LCAs) are interrelated, because LCA is a method for analysing and assessing the environmental impact of a material, product or service throughout its entire life cycle, usually from the acquisition of raw materials to final disposal (Jönsson, 2000). The importance of the interconnectivity of both LCAs and BEAs has been extended because most available BEAs do not take into account lifetime parameters (Sinou and Kyvelou, 2006). Instead, assessments are performed based on original conditions and characteristics, whereas alterations of the attributes of the building elements are not taken into consideration. Several widely used BEA rating systems are discussed in the next section. LCAs used in BEAs for integrated building design are discussed in the subsequent section.

2.3.2 Building environmental assessment methods-Rating systems

GBC

GBC (Green Building Challenge, GBTool) was first developed by Natural Resources, Canada, but responsibility was handed over to the International Initiative for a Sustainable Built Environment (IISBE) in 2002. GBC is an international collaborative effort to develop an environmental assessment tool for buildings that exposes and addresses controversial aspects of building performance and from which participating countries can selectively draw ideas for either incorporation into or modification of their own tools (Cole and Larsson, 1999). The assessment framework consists of the definition, structuring and scoring of a range of collectively agreed performance criteria and a software tool is provided to operationalize the framework (Cole and Larsson, 2001). In this regard, two versions of the software, namely GBTool 1 (GBC 98) and GBTool 2 (GBC 2000), have been developed. Each version uses six general performance areas, out of which three criteria are considered core requirements. Resource consumption, environmental loadings and indoor environmental quality are the core requirements in GBC 2000, while there is a subtle difference of naming in GBC 98 (Cole and Larsson, 2001). Table 2.1 shows all six criteria in both GBC 98 and GBC 2000.

Table 2.1: Green performance criteria in GBC 98 and GBC 2000

Green performance Criteria	
GBC 98	GBC 2000
1. Resource consumption	1. Resource consumption
2. Environmental loadings	2. Loadings
3. Quality of indoor environment	3. Indoor environmental quality
4. Longevity	4. Quality of service
5. Process	5. Economics
6. Contextual factors	6. Pre-operations management

Source : (Cole and Larsson, 2001)

Although it came originally with six criteria, Seo (2002) has added one more criterion for GBTool 2000, commuting transport. Moreover, he has provided four core criteria for the assessment, including “Resources consumption”, “Environmental loadings”, “Indoor environmental quality” and “Service quality”. Sinou and Kyvelou (2006) have also developed seven criteria in their review of present and future building performance assessment tools, but with differences in some terms. The tool provides a generic framework adding sub-criteria under each main criterion. Table 2.2 and Table 2.3 illustrate the criteria and sub-criteria used in the studies by Seo (2002) and Sinou and Kyvelou (2006) respectively.

Table 2.2: Assessment criteria for GBC according to Seo (2002)

Criteria	Sub-criteria
Resource consumption	1 Life cycle energy use 2 Land use 3 Net use of water 4 Net consumption of materials
Environmental loadings	1 Emission of greenhouse gases 2 Emission of ozone-depleting substances 3 Emission of gases leading to acidification 4 Solid wastes 5 Liquid effluent 6 Environmental impacts on site and adjacent sites
Indoor environmental quality	1 Air quality and ventilation 2 Thermal comfort 3 Day lighting illumination and visual access 4 Noise and acoustics 5 Electromagnetic pollution
Service quality	1 Flexibility and adaptability 2 Controllability of systems 3 Maintenance of performance 4 Quality of amenities and site development
Economics	1 Life cycle cost 2 Capital cost 3 Operating and maintenance cost
Pre-operation management	1 Construction process planning 2 Performance tuning 3 Building operations planning
Commuting transport	1 Greenhouse gas emission 2 Acidification gas emission 3 Photo-oxidant formation gas emission

Source: (Seo, 2002)

Table 2.3: Assessment criteria for GBC according to Sinou and Kyvelou (2006)

Criteria	Sub-criteria
Site selection	1 Site selection 2 Project planning 3 Urban design and site development
Energy and resource consumption	1 Total life cycle non-renewable energy 2 Predicted electrical peak demand for building operations 3 Renewable energy 4 Commissioning of building systems 5 Materials 6 Potable water
Environmental loadings	1 Greenhouse gas emissions 2 Other atmospheric emissions 3 Solid wastes 4 Rainwater, stormwater and wastewater 5 Impacts on site 6 Other local and regional impacts
Indoor environmental quality	1 Indoor air quality 2 Ventilation 3 Air temperature and relative humidity 4 Delighting and illumination 5 Noise and acoustics
Functionality	1 Functionality and efficiency 2 Design for maintenance of core functions outside of planned design conditions 3 Controllability
Long-term performance	1 Flexibility and adaptability 2 Maintenance of operating performance
Social and economic aspects	1 Cost and economics 2 Social aspects

Source: (Seo, 2002, Sinou and Kyvelou, 2006)

GBTool no longer exists under that name, and Sustainable Building Tools (SB Tool) has taken its place. The change occurred due to the concept changing from GBC to Sustainable Built Environment (SBE) (Weerasinghe, 2012). The latest version of SBTool (2012) features more factors in building assessment. Table 2.4 illustrates the criteria and sub-criteria considered in SBTool (2012) based on (Larsson, 2012).

Table 2.4: Assessment criteria of SBTool (2012)

Criteria	Sub-criteria
Site selection	1 Site selection 2 Off-site service available 3 Site characteristics
Site regeneration and development, Urban design and infrastructure	1 Site regeneration and development 2 Urban design 3 Project infrastructure and services
Energy and resource consumption	1 Total life cycle non-renewable energy 2 Electrical peak demand for facility operations 3 Use of materials 4 Use of potable water, Stormwater and Grey water
Environmental loadings	1 Greenhouse gas emissions 2 Other atmospheric emissions 3 Solid and liquid wastes 4 Impacts on site 5 Other local and regional impacts
Indoor environmental quality	1 Indoor air quality and ventilation 2 Air temperature and relative humidity 3 Delighting and illumination 4 Noise and acoustics 5 Control of electromagnetic emissions
Service quality	1 Safety and security 2 Functionality and efficiency 3 Controllability 4 Flexibility and adaptability 5 Optimization and maintenance of environmental operating performance
Social, cultural and perceptual aspects	1 Social aspects 2 Culture and heritage 3 Perceptual
Cost and economic aspects	1 Cost and economics

Source: Larsson (2012)

The assessment of SBTool follows a combined weighting and scoring system. The weighting system uses five main factors to evaluate the weighting of a sub-criterion. Each factor has a point score, which will be decided through defined terms linked to the score. Figure 2.2 shows the weighting factors and how point scores are assigned to the weighting factors (Larsson, 2012). The total weighting of a sub-criterion is given by the multiplication of A, B, C, D and E. Based on the active criteria for the building, the weighting is converted to a percentage.

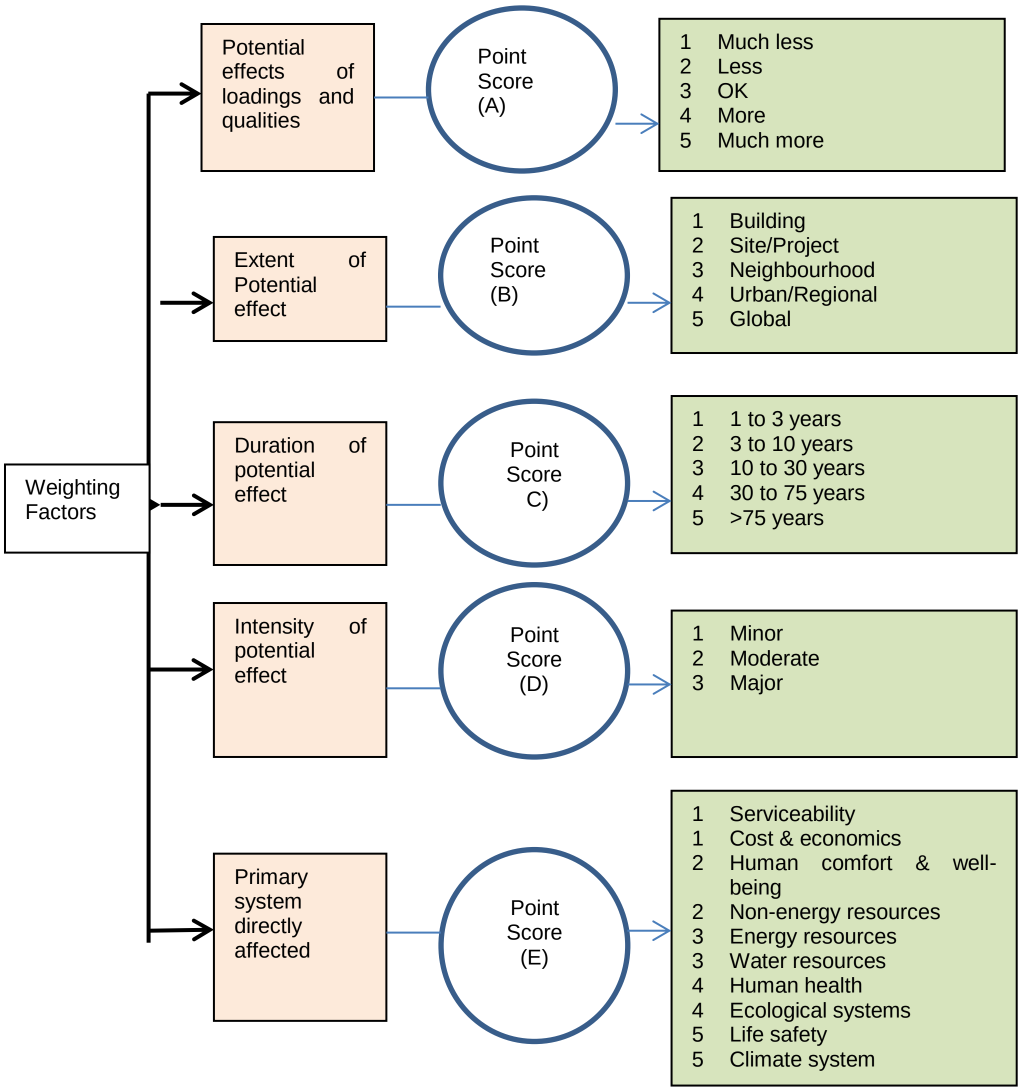


Figure 2.2: Weighting factors of the weighting system in SBTool 2012

Source: (Larsson, 2012)

The scoring process in SB Tool relies on a series of comparisons between the characteristics of the object building and national or regional references for minimally acceptable practice, “Good” practice and “Best” practice (Larsson, 2012). Accordingly, all criteria and sub-criteria are scored based on levels of acceptability for occupancy from -1 to 5, where -1 = unacceptable practice, 0 = minimum acceptable practice, 3 = good practice, 5 = best practice and 1, 2 and 4 represent varying degrees of performance between the above benchmarks. The whole process is followed through weighted scores. Targeted or self-assessed scores are multiplied by appropriate weights of all criteria to calculate weighted scores. Aggregation of individual weighted scores then forms the aggregated score, which gives an indication of the building condition. Figure 2.3 shows the schematic flow chart of the process of weighting and scoring for SBTool 2012.

Figure 2.3: Schematic flow chart of SBTool scoring and weighting

Source: (Larsson, 2012)

BREEAM

Building Research Establishment Environmental Assessment Method (BREEAM) was developed by the Building Research Establishment Limited in the UK.

> *BREEAM can be used to assess the environmental performance of any type of building, new and existing, anywhere in the world. BREEAM is an internationally recognised brand across the world, setting the standard for sustainability in the built environment. More than 300 buildings outside the UK have now been registered for assessment (Building Research Establishment Ltd UK, 2013).*

The launch of the first two versions of BREEAM assessment covering offices and homes occurred in 1990 (Building Research Establishment Ltd UK, 2013). Hence, BREEAM is the world's oldest building rating system. The key feature of BREEAM is that it has different versions (BREEAM Offices, BREEAM Eco homes, BREEAM Industrial and so on) depending on various building types. BREEAM can be applied to evaluate the environmental performance at any stage of the building, whether it is in design, construction or operation. BREEAM is basically implemented to assess buildings in the UK, but can be used to assess buildings outside the UK (WD Rethinking Ltd, 2010, Crawley and Aho, 1999).

The assessment is mainly based on credits given to a set of criteria in nine categories (WD Rethinking Ltd, 2010). Table 2.5 shows the criteria with their detailed descriptions, which are used for evaluating the environmental weightings. Credits are awarded to sub-elements of each category according to their performance and they are added together. Then the environmental weighting (percentage) is applied to scores within each category, which produces a single overall score. This score is incorporated in a scale, which is used to rate the building. Table 2.6 shows the rating corresponding to the percentage score.

Table 2.5: Assessment criteria in BREEAM (2008)

Criteria	Description
Management	1. Policy issues 2. Commissioning issues 3. Procedural issues
Health & well-being	1. Day lighting 2. Sound insulation 3. Private space
Energy	1. CO_2 emission 2. Building envelope performance 3. Drying space 4. Eco labelled white goods 5. External lighting
Transport	1. Public transport 2. Cycle storage 3. Local amenities 4. Home office
Water	1. Internal water use 2. External water use
Materials	1. Timber: basic building elements 2. Timber: finishing elements 3. Recyclable materials 4. Environmental impact of materials
Waste	1. Construction waste 2. Recycling
Land use & ecology	1. Ecological value of site 2. Ecological enhancement 3. Protection of ecological features 4. Change of ecological value on site 5. Building footprint

Sources: (WD Rethinking Ltd, 2010, Seo, 2002, Sinou and Kyvelou, 2006)

Table 2.6: Rating scales in BREEAM (2008)

BREEAM Rating	% Score
Unclassified	<30
Pass	≥30
Good	≥45
Very good	≥55
Excellent	≥70
Outstanding	≥85

Source: (Weerasinghe, 2012)

LEED

The Leadership in Energy and Environmental Design (LEED) rating system came into effect under the patronage of the United States Green Building Council (USGBC) over the period from 1994 to 1998 (Gu et al., 2006). The rating system is voluntary, consensus-based and market-driven, based on existing proven technology. LEED is now the most widely used rating system in the USA. As a result, it has made a major impact in the design and construction of buildings there for the last decade (Weerasinghe, 2012).

LEED is based on accepted energy and environmental principles and strikes a balance between known effective practices and emerging concepts (Seo, 2002). Its self-assessing rating system has the ability to rate different buildings, whether new or existing, including commercial buildings, institutional buildings and high-rise residential buildings (Seo, 2002, Weerasinghe, 2012). The rating of the building is given using a streamlined green building certification system based on earned credits for criteria for the different categories after meeting prerequisites. Table 2.7 shows the seven key performance categories and the number of prerequisites and criteria associated with them. It also depicts the possible points allocated to each category according to the criteria. Four ratings are awarded to buildings according to the total points earned through the criteria. Table 2.8 classifies the range of points required for the ratings.

Table 2.7: LEED Canada (2009) categories

Category	Prerequisites	Number of Criteria credits are assigned	Possible points
1. Sustainable sites	01	14	26
2. Water efficiency	01	03	10
3. Energy and atmosphere	03	06	35
4. Materials and resources	01	08	14
5. Indoor environmental quality	02	15	15
6. Innovation in design	-	02	06
7. Regional priority	-	02	04
Total	08	50	110

Source:: (Weerasinghe, 2012)

Table 2.8: LEED ratings

Rating	Points
Certified	40-49
Silver	50-59
Gold	60-79
Platinum	80 and above

Source: (Weerasinghe, 2012)

CASBEE

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) was established by the Japan Green Building Council, based on work by the government, academia and industry (Weerasinghe, 2012). The system of the assessment comprises four assessment tools which are capable of being used at different stages of the life cycle of the building, namely; pre-design,, new construction, existing and renovation (Weerasinghe, 2012, Seo, 2002). CASBEE was primarily intended to be a self-assessment system that allows users to evaluate the environmental performance of their buildings. However, it acts as a labelling system if a third party is involved in the assessment (Weerasinghe, 2012).

The method of assessment starts with the consideration of two major criteria: environmental quality and performance, and the reduction of environmental loadings. Two criteria are then assessed with sub-criteria. The detailed assessment criteria used in CASBEE are shown in Table 2.9. According to the table, three levels of criteria can be seen and assessment results are obtained following these levels. A five-level scoring system is used to obtain the score at the third level. For example, a score of “3”, which indicates “average”, is given to sub-criteria of noise and acoustics. Also, each assessment item is assigned a weighting co-efficient, and actual scores are calculated by multiplying both weighting co-efficient values and scores.

Table 2.9: Assessment criteria in CASBEE

Criteria		Re-criteria	Sub-criteria
Building environmental quality and performance	Indoor environment	Noise and acoustics	Noise, Sound insulation, Sound absorption
		Thermal comfort	Room temperature control, Moisture control, Type of air conditioning system
		Lighting and illumination	Day lighting, Anti-glare measures, Illumination levels, Lighting control ability
		Air quality	Sources control, Ventilation, Operation plan
	Quality of service	Service ability	Functionality and workability, Mentality: coziness
		Durability	Earth quake-resistance, Daily maintenance/updating
		Feasibility and adaptability	Space margin, Floor load margin, Adaptability of facilities
	Outdoor environment on site	Maintenance and creation of ecosystem	-
		Town scape and landscape	-
		Local characteristics and culture	-
Reduction of building environmental loadings	Energy	Building thermal load	Building orientation, Thermal load of windows, Insulation level of exterior wall and roof
		Natural energy utilization	Direct utilization of natural energy, Indirect utilization of natural energy
		Efficiency in building system	HVAC system, Ventilation system, Lighting system, Water heating system, Elevator system
		Efficient operation	Monitoring operational management system
	Resources and materials	Water resource	Water saving, Utilization of rain water and gray water
		Eco-materials	Use of recycled materials, Use of wood and natural materials, Use of hazardous materials, Reuse of existing skeleton, etc., Waste disposal, Avoidance of CFCs and Halons
	Off-site environment	Air pollution	Emission of air pollutants, emission of water pollutants, Emission of soil pollutants
		Noise and offensive odours	Noise generation, Offensive odours
		Wind damage	-
		Lighting damage	-
		Heat island effect	-
		Load on local infrastructure	Load on sewage treatment systems, Load on traffic management systems, Load on waste management system

Source: (Seo, 2002)

<u>NABERS</u>

The National Australian Building Environmental Rating System (NABERS), of which the development started in 2001, is Australia's first comprehensive rating system for existing operational buildings. Currently, it is also capable of being applied to new buildings. In addition, the scope of the application has been widened to commercial and residential types of building, both new and existing. The assessment of NABERS is based on a series of questions which takes into account both building and user considerations. The answers to the questions can be given by the building owner or user without the need for specialist assessors, which makes the assessment system of NABERS appropriate for a voluntary rating system.

The NABERS commercial and domestic rating methods both include of eight headings each with a number of sub-headings. The eight main headings are: land, materials, energy, water, interior, resources, transport and waste. The overall score for each heading is derived from the average of the scores of the sub-headings. The overall scores are expressed with number of stars: the better the environmental performance, the higher the number of stars. All sub-headings of NABERS measure the performance on a rating scale from 1 to 6 stars. Each star means a level of performance expressed in words, as shown in Table 2.10. The overall score for a building is decided according to the minimum number of stars obtained for each main heading. If each main heading has scored at least 4 stars, then the overall score of the building is 4 stars.

Table 2.10: The NABERS rating scale

Number of stars	Linguistic meaning given for the performance
6	Market leading performance
5	Excellent performance
4	Good performance
3	Average performance
2	Below average performance
1	Poor performance

Source: (Office of Environment and Heritage NSW Government, 2013)

GREEN STAR

The Green Star environmental rating system was launched by the Green Building Council of Australia in 2003 to transform the Australian building market in terms of two main objectives (Green Building Council of Australia, 2013). They are:

- towards **sustainability** by promoting green building programs, technologies, design practices and operations
- towards **integration** of green building initiatives into mainstream design, construction and operation of buildings

The assessment has adapted some existing BEA methods, mainly BREEAM and LEEDS, to suit the Australian industry. The rating system initially addressed office buildings, but it has evolved to be used in industrial, educational, healthcare buildings, among others.

The Green Star system assesses and rates buildings in different sectors (e.g. commercial buildings, retail centres, schools and universities) against a range of environmental impact categories. They are:

- Management
- Indoor Environmental Quality
- Energy
- Transport
- Water
- Materials
- Land Use and Ecology
- Emissions
- Innovation

The Green Star rating tools award points for the achievement of specific credits in each rating category. Then, the score of each category is determined as a percentage from the following equation:

$$\text{Category Score}=\frac{\text{No. of Points Achieved}}{\text{No. of Points Available}}\times 100\%$$

................Equation 2.1

When the category score has been calculated, the following steps are taken in sequence in order to determine the overall score of a project or building.

1. Apply an environmental weighting to each category

2. Add all weighted category scores together

3. Add any innovation points that may have been achieved

Depending on the overall score, a number of stars are given. The range of points assigned to the number of stars and the interpretations are shown in Table 2.11.

Table 2.11: Green Star Rating

Green Star Rating	Range of points	Interpretation
One Star	10 - 19	Minimum Practice
Two Star	20 - 29	Average Practice
Three Star	30 - 44	Good Practice
Four Star	45 - 59	Best Practice
Five Star	60 - 74	Australian Excellence
Six Star	75 or more	World Leadership

Source: (Green Building Council of Australia, 2013)

<u>*GREEN GLOBES*</u>

> *The Green Globes system is a revolutionary building environmental design and management tool. It delivers an online assessment protocol, rating system and guidance for green building design, operation and management. It is interactive, flexible and affordable, and provides market recognition of a building's environmental attributes through third-party verification (Green Globes, 2013).*

Based on BREEAM, the first Green Globe rating system emerged in 2000 in Canada for existing buildings and it was followed by a Green Globe rating system in 2002 for new buildings. A total of 1000 points are distributed among sub-criteria under six main criteria in the Green Globe assessment. The six main criteria, the total points allocated for each criterion, and the allocation of those points as a percentage are shown in Table 2.12.

Table 2.12: Main areas of the assessment of Green Globes

Main area	Points allocated	Points allocated as a percentage
Project management	50	5%
Site	115	11.5%
Energy	380	38%
Water	85	8.5%
Resources	100	10%
Emissions, effluents and other impacts	70	7%
Indoor environment	200	20%

Source: (Weerasinghe, 2012)

HQE

HQE is a national certification system in France for non-residential buildings such as offices, schools, hotels and shopping centres. The system identifies 14 environmental issues and covers two areas: the environmental quality of the building and the environmental management of the entire project (Boonstra and Pettersen, 2003). The HQE-defined 14 environmental issues fall into four main categories as follows: (1) eco-construction and eco-management, which are related to the exterior environment and (2) Comfort and health which are related to the interior environment.

Eco-construction

1. Harmonious relationship between buildings and their immediate environment

2. Integrated choices of construction processes and materials

3. Low-nuisance construction sites

Eco-management

4. Energy management

5. Water management

6. Waste management

7. Repair and maintenance management

Comfort

8. Hygrothermal comfort

9. Acoustic comfort

10. Visual comfort

11. Olfactory comfort

Health

12. Sanitary conditions of indoor spaces

13. Air sanitary quality

14. Water sanitary quality

Three rating scales, “basic”, “good” and “very good”, are used to assess the level of performance of these 14 issues in relation to current regulations or normal practice. Certification is granted upon the achievement of a “minimum profile” according to set rating scales for environmental issues. “Very good” certification is granted if at least three issues receive “very good” ratings, while at least four “good” ratings are required for environmental issues for a “good” certification. For a “basic” certification, seven or more targets should be met at a “basic” level.

VERDE

VERDE is a Spanish method for evaluating the environmental performance of new buildings, and is applicable to various building types, including residential, offices, commercial, hotels, hospitals and educational. The system covers a wide range of sustainable building issues, environmental loadings, resources exhaustion, emission to air, water and solid wastes, local and regional impacts, factors affecting building environment, indoor environment quality and quality of service, as well as social and economic factors (Sinou and Kyvelou, 2006). The criteria and parameters are presented in Table 2.13.

Table 2.13: Criteria and parameters involved in the VERDE method

Criteria	Parameters
Resources exhaustion	Depletion energy resources, Depletion raw materials, Water use and water management, Emission to air, water and solid wastes
Local and regional impacts	Impact of building to the surrounding buildings, Heat island effect, atmospheric light pollution
Indoor environment	Noise and acoustics, Thermal comfort, Lighting, Air quality
Quality of service	Functionality and controllability, Flexibility and adaptability, Durability and maintenance, Waste management
Economic aspects	Cost of land and construction, Life cycle cost, waste management and emission costs
Social aspects	Health and productivity, Security for building users, Access for physically handicapped persons, Access to direct sunlight from living areas of dwelling units, Visual privacy from the exterior in principal areas of dwelling units, Access to views from work areas on offices and other commercial buildings

Source: (Sinou and Kyvelou, 2006)

The assessment is mainly based on the GBTool, using benchmarks and weights appropriately for each criterion. A value scale is introduced to evaluate the performance ranging from 0 to 5, with 0 representing the reference scale or minimum acceptable performance, and five representing the best practice or maximum performance achieved using the best available technology with affordable cost.

CRITICAL REVIEW ON BUILDING ENVIRONMENTAL ASSESSMENTS

Three different criteria are used to critically review the environmental assessments discussed above. First criterion of them distinguish the level of assessment whether its focus is narrowed to “building product” or little widened to “building” or broadened to “community”. All the models considered here focus on buildings. The second criterion is the types of criteria covered in the assessment. Review here selected five broader criteria for the purpose such as “resource consumption”, “environmental loading”, “indoor environmental quality”, “economics” and “social concerns”. Table 2.14 shows all types of criteria covered by each model. Data shows that except GBC and VERDE, all other models do not include economic considerations into their assessments. It also shows that only VERDE takes social concerns into consideration for the assessment, not any other model.

Table 2.14: Types of criteria covered in each model

		Model								
		GBC	BREEAM	LEED	CASBEE	NABERS	GREEN STAR	GREEN GLOBES	HQE	VERDE
Criteria type	Resource consumption	√	√	√	√	√	√	√	√	√
	Environmental loading	√	√	√	√	√	√	√	√	√
	Indoor environmental quality	√	√	√	√	√	√	√	√	√
	Economics	√	–	–	–	–	–	–	–	–
	Social concerns	–	–	–	–	–	–	–	–	√

The third and last criterion checks the weighting system applied in the assessment. Table 2.15 gives a brief description of the weighting system of each model. Data proves that there is no scientific or mathematical based weighting system embedded with any of the models. However, Models like CASBEE follows a consensus based weighting system which appears to be a comparatively better approach.

Table 2.15: Weighting systems applied in each model

Model	Weighting system
GBC	Default or modified weights
BREEAM	Fixed weights
LEED	Equal weights to all criteria
CASBEE	Relative importance values summed up to 1
NABERS	No specific weighting system
GREEN STAR	Default weighting to each environmental category
GREEN GLOBES	Similar to BREEAM
HQE	No specific weighting system
VERDE	Similar to GBC

SUMMARY OF BUILDING ENVIRONMENTAL ASSESSMENTS

Nine different assessment methods, GBC, BREEAM, LEED, CASBEE, NABERS, GREEN STAR, GREEN GLOBES, HQE, VERDE, have been reviewed under the heading of building environmental assessment methods. The review enables an understanding of the critical factors or criteria which have an impact on the sustainable management of buildings. It has also provided a great deal of information about the methods followed in the assessment process. The lists of factors used in the reviewed assessment methods indicate that most factors are related to environmental sustainability. Of the other factors, some consideration is given to economic, social and functional factors which combine with the environmental factors to produce the total sustainability rating. Although none of the assessments covers all four factors, the present research proposes to measure total sustainability in a broad way with four factors. Review also suggested a lack of scientific or mathematical based weighting system applied in current building environmental assessments.

2.3.3 Life cycle assessment approaches used in environmental assessment of buildings

Life cycle assessment (LCA) is based on the standards initiated by the International Organization for Standards (ISO)(Keeler and Burke, 2009). According to ISO standard 14040, LCA comprises four distinctive phases: goal and scope definition, inventory analysis, impact assessment, and interpretation (I.S.O., 2006).

BEES

Building for Environmental and Economic Sustainability (BEES) was developed by the National Institute of Standards and Technology, USA. The BEES tool implements a rational, systematic technique for selecting cost-effective green building products. It offers a decision support software tool for designers, builders, and product manufacturers, combined with environmental and economic performance data for 65 building products (in Version 2) across a range of functional applications (Lippiatt and Boyles, 2001). The performance data are normalised and weighed through inventory and impact analysis until the summation of each captures a single score, which is called eco-efficiency score. The process adopts life-cycle approach of which the life-cycle is shown in Figure 2.4. Furthermore, the process follows three consensus standards: Environmental Life-Cycle Assessment (ISO 14040), Life-Cycle Costing (ASTM E917), and Multi-attribute Decision Analysis (ASTM E1765) (Lippiatt, 2007).

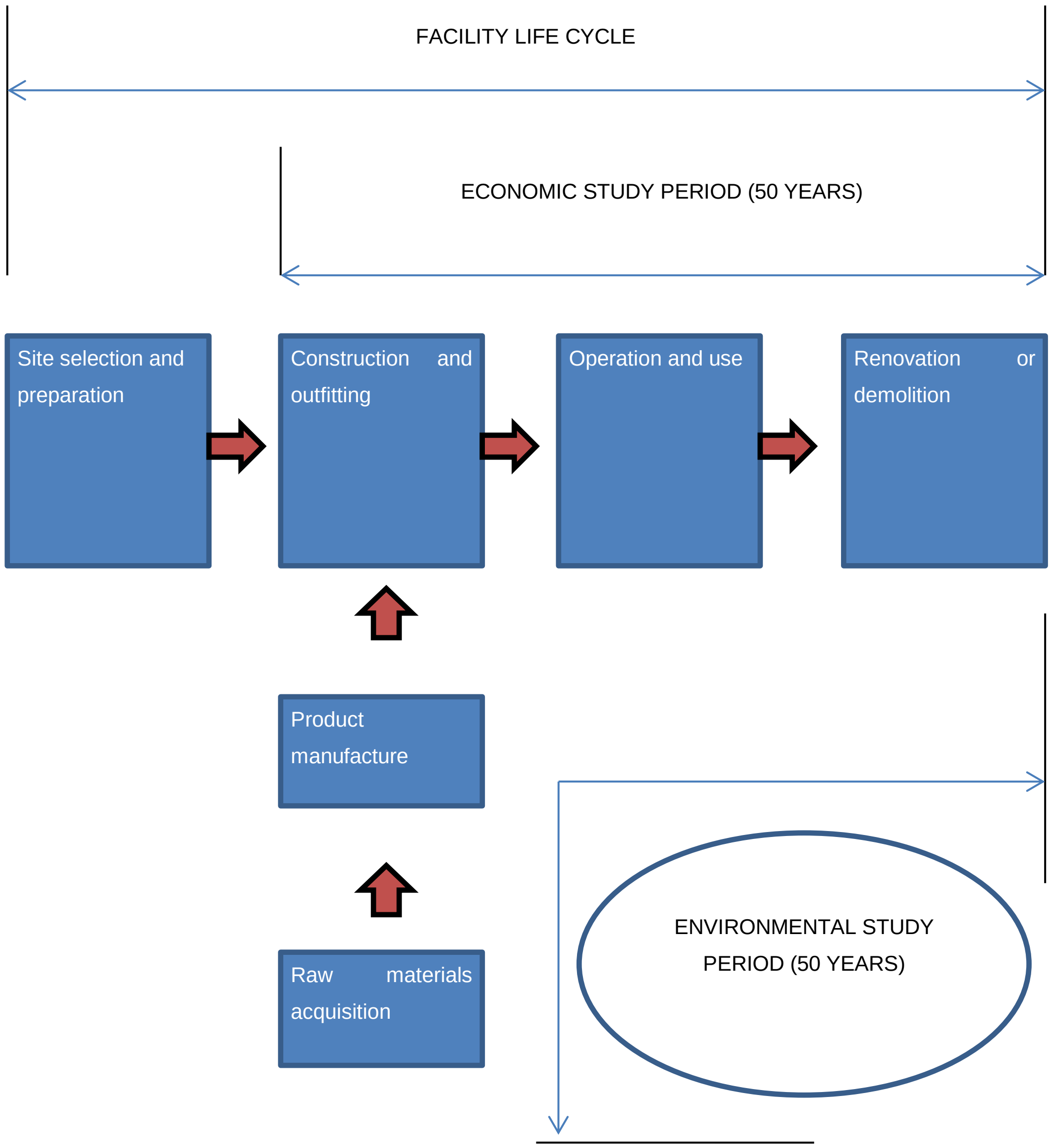


Figure 2.4: BEES life-cycle representation

Source: (Lippiatt, 2007)

The BEES calculates the environmental performance of building products using twelve main impact categories (Figure 2.5). Each impact category is given a normalized impact assessment result (performance score) based on inventory data and impact analysis. Then, each performance score is synthesized to evaluate the overall environmental performance of the building product. In this regard, the weighting percentage of each impact category is considered with respect to the overall environmental performance. Moreover, the weighting calculation is guided by the ASTM E1765 standard, in which a Multi-Attribute Decision Analysis (MADA) method, known as the Analytical Hierarchical Process (AHP) (Saaty, 1990), is utilised to calculate the weighting. The summation of individual weighted scores gives rise to the overall environmental performance score.

Economic performance is measured by two criteria (Figure 2.5) with readily available data. First, cost data is collected from the R.S. Means publication, 2007 Building Construction Cost Data and industry interviews, while future cost data are based on data published by Whitestone Research in The Whitestone Building Maintenance and Repair Cost Reference 2006-2007 and industry interviews (Lippiatt, 2007). The most appropriate method for measuring the economic performance of building products is the life-cycle cost (LCC) method. Hence, BEES follows the ASTM standard method for life-cycle costing of building-related investments (Lippiatt, 2007). Once both environmental and economic performance scores are calculated, they are amalgamated to find the overall performance score (eco-efficiency score). MADA is the appropriate method for combining results of two diverse ends into a valid output. A similar method applied previously to calculate the overall environmental performance is followed to obtain the eco-efficiency score of the product.

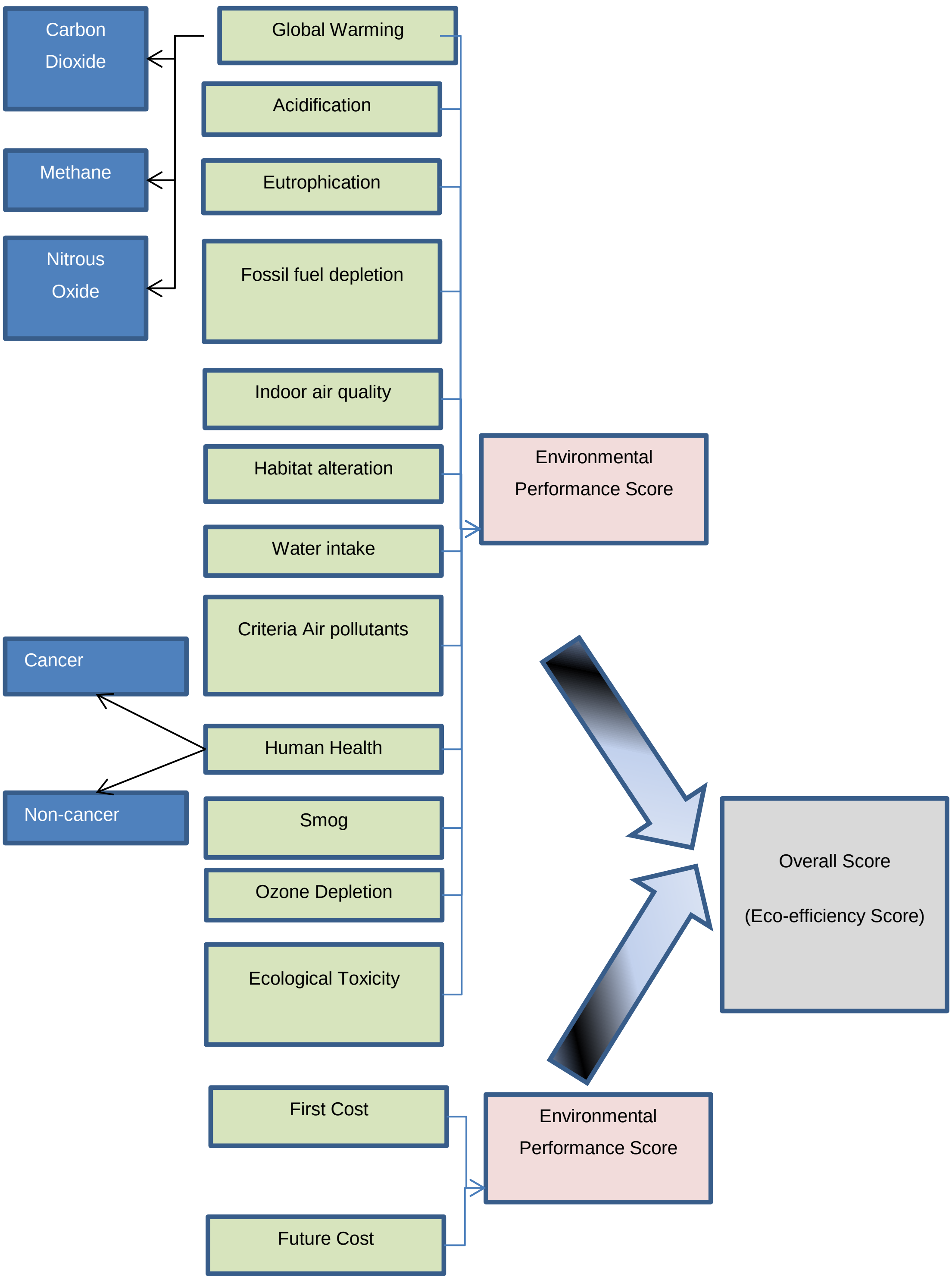


Figure 2.5: Schematic overview of the assessment process of BEES

Source: (Lippiatt, 2007)

<u>LCAid</u>

LCAid™ is a computer software tool developed for the NSW Department of Public Works and Services (DPWS) by Dr. Andrew Marsh. The software's aim is to make LCA more accessible to design and building practitioners for environmental assessment and design improvement (Eldridge, 2002). LCAid™ arose from the need to provide a fast, comprehensive and scientifically-based environmental assessment of buildings. It is aimed at the building designer, and is a user-friendly decision-making tool, using LCA methodology to evaluate the environmental performance of design options and to identify the largest impacts over the entire life cycle of a building (Eldridge, 2002).

Three types of input data are required for the software (Graham, 2003). They are:

1. General Information

- Building type
- Number of occupants
- Region for climate data

2. Material type and quantity

Select materials from the LCA library of materials and enter the quantities.

3. Waste generation, water and energy use

These are automatically generated from the building design information.

The assessment system in LCAid uses eco-performance criteria. The list of criteria is shown in Table 2.16. Based on the criteria, LCAid evaluates the environmental impact of a building over its whole life.

Table 2.16: Assessment criteria in LCAid

Criteria (Performance)		Items considered in LCAid
Resource	Energy consumption	Energy
Environmental Loading	Water consumption	Water
	Greenhouse effect	CO_2, CFCs, HCFCs, Halons, Methane, N_2O, Other chlorinated hydrocarbons
	Ozone depletion	CFCs, HCFCs, HFCs, Halons, Other chlorinated hydrocarbons
	Heavy metals	Cadmium, Murcury, Lead, Arsenic, Copper, Nickel, Manganese, Chrome
	Nutrification	Ammonia, Nitrates, NOx, SO_2, Sox
	Acidification	Ammonia, HCI, HF, NO, NO_2, NOx, SO_2, Sox
	Carcinogenesis	Aromatic hydrocarbons, and derivatives
	Summer smog	Chlorinated hydrocarbons, Alcohols, Aldehydes, Saturated and unsaturated hydrocarbons, Mercaptans, Aromatic hydrocarbons, Volatile organic compounds, Ketones, Phenols
	Winter smog	Dust, SO_2
Economics		Life cycle cost

Source: (Seo, 2002)

ENVEST

ENVEST (Environmental impact estimating design software) is a BEA tool developed by the Building Research Establishment (BRE) in the UK, and is the first UK software tool that estimates the life cycle environmental impacts of a building from the early design stage (Seo, 2002). ENVEST2 is the updated version currently in use that allows both environmental and financial trade-offs to be made explicit in the design process, allowing the client to optimise the concept of best value according to their own priorities (ENVEST2, 2013). It helps to predict elements with most influence on a building's environmental impact as well as the effects of choices in building operations and services.

ENVEST2 is web-based, allowing large design companies to store and share information in a controlled way, enabling in-house benchmarking and design comparison. Two versions of the tools are available:

- ENVEST2 estimator
- ENVEST2 calculator

The software requires input data in two forms:

- Quantitative: length, width, plan depth, number of storeys, storey height, gross area, glazing area, operational life, ground floor, upper floor area, external (internal) walls area, roof area, window area, lighting load, water consumption
- Qualitative: building type, location, soil type, heating (boiler and heating system), light switch control, ventilation type, cooling system, lift type and capacity

The software uses an eco-point rating system based on BRE's environmental profile database as well as a whole life cycle costing database. Accordingly, several criteria are used in the assessment, as shown in Table 2.17.

Table 2.17: Assessment criteria in ENVEST 2

Criteria	Description
Resource Consumption	Operational Energy, Water Use, Material Consumption, Water Extraction, Fossil Fuel/Minerals Depletion, Waste Disposal
Environmental Loading	Ambient Air, Climate Change, Acid deposition, Human Toxicity and Ozone depletion, Transport Pollution and Congestion, Water Eutrophication Eco-toxicity
Indoor Air Quality	Ventilation, Day Lighting, Thermal Comfort, Min IAQ
Economics	Whole Life Costs

Source: (Watson et al., 2004)

<u>CRITICAL REVIEW ON BUILDING LIFE CYCLE ASSESSMENTS</u>

Similar criteria followed in the critical review of environmental assessments are used for critically reviewing life cycle assessments. Hence, assessment level is checked for the purpose of first criterion. Except BEES, all other models focus on buildings for their assessment. Building product is the focus of BEES. Types of criteria are investigated in all three models to check the second criterion of the critical review. Table 2.18 captures the types of criteria of each model. Data shows that only BEES and LCAid models are concerned of economic factors, not ENVEST. However, no model captures social concerns into their assessments.

Table 2.18: Types of criteria

		Model		
		BEES	LCAid	ENVEST
Criteria type	Resource consumption	√	√	√
	Environmental loading	√	√	√
	Indoor environmental quality	√	√	√
	Economics	√	√	–
	Social concerns	–	–	–

Weighting system is the third criterion used in the critical review of the assessments. Table 2.19 shows the weighting systems of each model. According to the table, BEES is comprised of a mathematical based weighting system which adopts Analytical Hierarchical Process (AHP) to obtain weightings. All other models carry common weighting systems far from comprehension.

Table 2.19: Weighting systems applied in each model

Model	Weighting system
BEES	Relative importance values based on AHP
LCAid	LCA based impact assessment
ENVEST	Similar to LCAid

<u>SUMMARY OF LIFE CYCLE ASSESSMENTS</u>

Similar to the previous section, the main purpose of this section is to understand the factors or criteria involved in assessments of sustainability, and the techniques involved in estimating life cycle impacts. Three different life cycle assessments, BEES, LCAid and ENVEST, are reviewed for the above purpose. The review has shown that life cycle assessments are mainly concerned with environmental and economic aspects. It also finds the weighting systems applied in the models, except BEES, are absence of a scientific or mathematical based system.

2.4 Building management models

2.4.1 Background

Management in all business and organizational activities combines the effective utilization of people and resources to accomplish desired goals and objectives. Facility management is a part of the whole management of all business and organizational activities. The term “facility” refers to a building where a particular activity happens for a particular purpose (Cambridge Advanced Learner's Dictionary, 2005). Hence, building management can be considered as coming under the umbrella of facility management.

The goal for a service-oriented asset, the class to which community buildings belong, is to not only meet the required level of service but also to provide the services cost-effectively, considering present and future stakeholders(IIMM, 2006). Based on this idea, there are different models to support building management, depending on the specific goal. In relation to service and costs, service life prediction is an important issue. Service life prediction deals with renewals, retrofits and maintenance of the building. The widely-used models for service life prediction are discussed in the following sub-sections.

2.4.2 The Factor Method

The factor method is a deterministic method of determining the estimated service life of a building component or assembly. A formula is developed and utilized for the purpose, in which input variables are the deterioration factors with the exception of the reference service life of the component (RSLC). The development of the deterioration factors follows two main criteria and their sub-criteria referred to as the Japanese Principle Guide for service life planning of buildings (Hovde and Moser, 2004). See Table 2.20.

Table 2.20: Criteria involved in developing deterioration factors of the Factor Method

Criteria	Sub-criteria
Inherent (durability) characteristics of performance over time	1. Performance of materials 2. Quality of design 3. Quality of construction work 4. Quality of maintenance and management
Environmental deterioration factors	1. Site and environmental conditions 2. Condition of building

RSLC can also be defined as the period in years that the component or assembly can be expected to last in a reference case under certain service conditions (Jernberg et al., 2004). Having taken into account both deterioration factors and RSLC, the final version of the formula used in the Factor Method is derived. The formula enables the determination of the estimated service life of building component as follows:

ESLC = RSLC x factor A x factor B x factor C x factor D x factor E x factor F x factor G

................Equation 2.2

where,

- ESLC is estimated service life of the component
- RSLC is reference service life of the component
- factor A is quality of components
- factor B is design level
- factor C is work execution level
- factor D is indoor environment
- factor E is outdoor environment
- factor F is in-use conditions
- factor G is maintenance level

2.4.3 EUROLIFEFORM (**EURO**pean **LIFE** Per**FORM**ance)

The main aim of the development of the EUROLIFEFORM model was to develop a generic model for predicting life cycle costs and performance applicable to new and existing buildings and civil infrastructure, using a risk-based and probabilistic approach (Bamforth, 2003). Five main features are included in the model to address key issues prevalent to building or infrastructure management. They are:

1. Mapping the decision process and development of the log book
2. Performance data and deterioration modelling
3. Cost data and financial modelling
4. Environmental and socio-economic impacts
5. Development of the life cycle cost and performance (LCCP) model

<u>Mapping the decision process and development of the log book</u>

Decisions are taken throughout the life of an asset and the log book has been designed to record the design input data (cost and performance), modelling assumptions and the actual costs and performance in service.

<u>Performance data and deterioration modelling</u>

Two approaches are used. The first uses historical data which are statistically presented. In this regard, values of service life for individual elements under the conditions of “minimum”, “maximum” and “most likely” are represented by the data. From such data, a distribution may be established (e.g. triangular) which can later be fed into a probabilistic model. To reflect project-specific conditions, such data will be transformed by applying the ISO factorial approach. Where historical data are not available or not directly applicable to new materials or elements, service life is defined as the time to achieve a maximum acceptable probability of the serviceability limit state being reached.

<u>Cost data and financial modelling</u>

A method has been established for utilising discounted cost within a risk-based approach to LCC.

Environmental and socio-economic impacts

Apart from the cost factor, significant environmental and socio-economic factors are required in the final decision. To enable such factors to be incorporated into the decision-making process, multi-criteria decision- making techniques are involved in the model. In this case, a system is introduced giving indices attached to different factors by means of assigned values of scoring, ranking and weighting.

Development of the life cycle cost and performance (LCCP) model

The probabilistic LCC calculator has been developed using Microsoft Excel and @Risk software applications. The model enables decision-making at three levels: strategic (client brief), concept design (system level to establish budgets) and detailed design (to develop detailed tender costs).

2.4.4 EPIQR

The main objective of the Energy Performance, Indoor Environmental Quality and Retrofit (EPIQR) model was to develop a software tool with a structured diagnosis scheme for existing buildings which covers the state of their degradation, energy performance and indoor air quality, and helps users to make informed decisions. It was also intended to construct a coherent refurbishment scenario and calculate a reasonable investment in the early stages of refurbishment projects (Flourentzou et al., 2001).

Three criteria are involved in assessment using EPIQR and its results enable the user to set up a refurbishment strategy. The three criteria are:

- Building deterioration state
- Heating/cooling energy requirement and energy saving potential
- Occupants and indoor environmental quality

The building is decomposed into 50 elements, including windows, façade finish, boiler, and electrical installation (Flourentzos et al., 2000a). For each building element, different types may exist. The user chooses the type that corresponds to the actual building and decides which of the deterioration codes (a, b, c or d) are applicable to best fit the observed state of the building element. The deterioration codes a, b, c and d are defined according to each building component such that ‘a’ represents the best state of the condition whereas ’d’ represents the worst state of the condition; ‘b’ and ‘c’ are intermediate states. In addition to the detailed description, one or more pictures illustrate the four possible deterioration states. A total of about 500 photos and sketches help the user to decide on the correct deterioration code. Once the deterioration state is identified, the program uses seven necessary coefficients to calculate the refurbishment cost. They are:

- Façade area
- Built area
- Area of foundations
- Lot area
- Number of apartments
- Number of stories
- Number of staircases

Energy calculation modules are then used to estimate the building energy balance and assess the energy conservation potential for space heating and cooling. Energy bills show the current state of the building energy consumption. This state is compared to the standard and best practice values of the country to illustrate the saving potential (Flourentzos et al., 2000b).

EPIQR collects data on the indoor environment and the quality of apartment facilities quality using a questionnaire directed to occupants before the building audit is carried out. The software performs a statistical treatment of the questionnaire and relates complaints to refurbishment work and energy retrofit measures. Accordingly, different possible actions for the improvement of the refurbishment can be selected.

The assessment on three criteria leads to building the best possible refurbishment scenario. A round graph summarizes the building deterioration state of the 50 building elements. On the same graph the user can visualize the refurbishment cost and identify the most expensive actions (Flourentzos et al., 2000b). The active energy flowchart assists the user to construct an energy coherent scenario by testing the effect of different projected actions (Flourentzos et al., 2000b). Cooling calculations give complementary information on the priorities for indoor environmental improvements by identifying the energy savings for each case so that any potential retrofit actions can be well targeted (Flourentzos et al., 2000b). Hence, the energy flow chart, the cooling module and the deterioration/ cost graph help the user to take a global attitude towards the refurbishment of a given project. The interface of the software is programmed in Microsoft Visual Basic 5 and the databases in MS Access 1997. About 350 European residential buildings were used as case studies and audited in order to collect the input data for the work that was performed.

2.4.5 MEDIC

Knowledge of the probable residual life span of a building element will often be decisive for whether it will be replaced or not (Flourentzou et al., 2000). According to Flourentzou et al (2000), the main aim of developing the MEDIC (Methode d'Evaluation de scenarios de Degradation probables d'Investissements Correspondants) software tool was to calculate the remaining life span of a building element, not as a deterministic unique value but as a probability distribution. The tool supports EPIQR by providing a number of random draws on the probability curves for each of the 50 elements (using the Monte-Carlo procedure) and calculating the cost for the resulting code combinations. Hence, the program can obtain the probability distribution of the global refurbishment cost.

As mentioned above, MEDIC is intended to work together with EPIQR, which is based on subdividing the building into 50 elements. Four codes, a, b, c, and d, identical to those of EPIQR, are used to describe the deterioration state of the elements. Code a represents an element in good condition, code b an element with minor deterioration, code c an element with more serious deterioration and code d an element that needs replacement. The knowledge base of the method is summarised in four probability curves for each building element. For a certain element, these curves show the probability for the deterioration code to be a, b, c or d at any time in the element's life time. After determining the present state and the quality subspace of an element, the posteriori probability of having code a, b, c or d for the years that follow the diagnosis can be determined.

2.4.6 TOBUS

TOBUS is the end result of a two year research program launched by the European Commission together with eight European institutions in 2002.

> *The main objective of the project was to develop an evaluation tool and software for the assessment of retrofitting needs of office buildings in European countries and for estimating the costs to meet these needs in compliance with improved energy performance and indoor environment. The tool encompasses an integral approach, where all problems are treated globally but also taking into account their inter-dependence. (Caccavelli and Gugerli, 2002).*

TOBUS diagnoses the general state of the office building and accordingly define actions for improvement. The decision-making procedures of TOBUS are applied at the retrofitting scenario level, of which the result is a proposal for a refurbishment strategy. The refurbishment strategy corresponds to global actions, along with their typical cost and impact on energy savings, and the improvement of indoor environmental quality. Hence, four main criteria are involved in TOBUS for the assessment of the best refurbishment strategy as follows:

1. Physical state of degradation of building elements
2. Functional obsolescence of building services
3. Energy consumption
4. Indoor environmental quality

2.4.7 Summary of building management models

In this section, different building management models are reviewed. Among the selected methods, the factor method and Eurolifeform focus on deterioration prediction, whereas the other models, EPIQR, MEDIC and TOBUS, emphasise the building retrofit aspect. All three models for retrofit purpose use three major criteria in their retrofit strategy. They are building deterioration state, energy consumption and indoor environmental quality. TOBUS considers functional obsolescence of building services as additional criteria using in the retrofit strategy along with three criteria above. Although they contribute to decision-making, none of the models is able to make decisions on maintenance actions on the basis of sustainability. The present research identifies the gap and proposes a model to address the gap. Apart from identifying gaps, a detailed review of these models was carried out for two purposes: 1. to capture any factors or criteria related to the sustainable management of buildings (four criteria mentioned above were captured) ; 2. to understand the state of the art of building management models.

2.5 Generic infrastructure asset management system

> *The Canadian Oxford Dictionary defines "infrastructure" as the basic structural foundation of a society or enterprise; roads, bridges, sewers, etc. regarded as a country's economic foundation. Many organizations are also using the term civil infrastructure systems (CIS) to describe this type of built asset to distinguish it from other forms of infrastructure such as computer networks (Vanier and Rahman, 2004).*
>
> *"Municipal infrastructure", a distinct portion of civil infrastructure, includes those assets managed by municipalities. These typically include, but are not restricted to, the following classes of assets: buried utilities, roads, transit systems, bridges, water/sewage treatment plants and parks. Some jurisdictions are responsible for a variety of*

buildings (i.e. police stations, fire halls, indoor swimming pools, arenas and community centres) but their responsibility could also extend to other types of buildings such as social housing, schools and vehicle maintenance depots (Vanier and Rahman, 2004).

2.5.1 Asset management

Some of the definitions of asset management are as follows:

> *Infrastructure asset management is the methodology to meet a required level of service in the most cost-effective way through the creation, acquisition, maintenance, operation, rehabilitation and disposal of assets to provide for present and future customers (IIMM, 2006).*

> *Asset management is a business process and decision-support framework that: (1) covers the extended service life of an asset, (2) draws from engineering as well as economics, and (3) considers a diverse range of assets (Vanier and Rahman, 2004).*

> *Asset management is a way of doing business. It is a tool used by both public and private entities to manage their assets so that they meet business and customer needs at the lowest possible cost over the longest possible period. Asset management means getting the right information to the right people at the right time, to obtain the right decision (Najafi et al., 2008).*

> *…..a strategic and systematic process of optimising decision-making in resources allocation with the goal of achieving planned alignment of infrastructure asset with service demand throughout its lifecycle (Too et al., 2006).*

Asset management is a customer-focused, goal driven management and decision-making process (FHWA, 1999).

It can be seen that all of the definitions emphasise the idea of cost-effectiveness. Some definitions identify the importance of incorporating decision-making with asset management. Decision-making has been identified as being capable of addressing issues such as optimum use of assets, effective maintenance, repairs, renewals and replacements, and standard inspection and monitoring systems. While the goals of asset management can be interpreted in these ways, there are core principles of asset management as follows (Neumann et al., 2003):

- Asset management is policy-driven
- Asset management is performance-based
- Asset management examines options and trade-offs at each level of decision-making
- Asset management bases decisions on merit
- Asset management maintains clear accountability

2.5.2 Strategic asset management system (Framework)

Each asset management practice can be represented by three sequential processes regardless of the differentiation between the practices, the infrastructure asset type being used in the practice or the managing body implementing the practice (Too et al., 2006). Hence, the processes of strategic analysis, strategic choice, and strategic implementation, can be fitted into a generic strategic asset management framework. Figure 2.6 shows a detailed view of process flow, illustrating internally reviewed data of each major process, in conjunction with capturing information and feedback throughout the whole process.

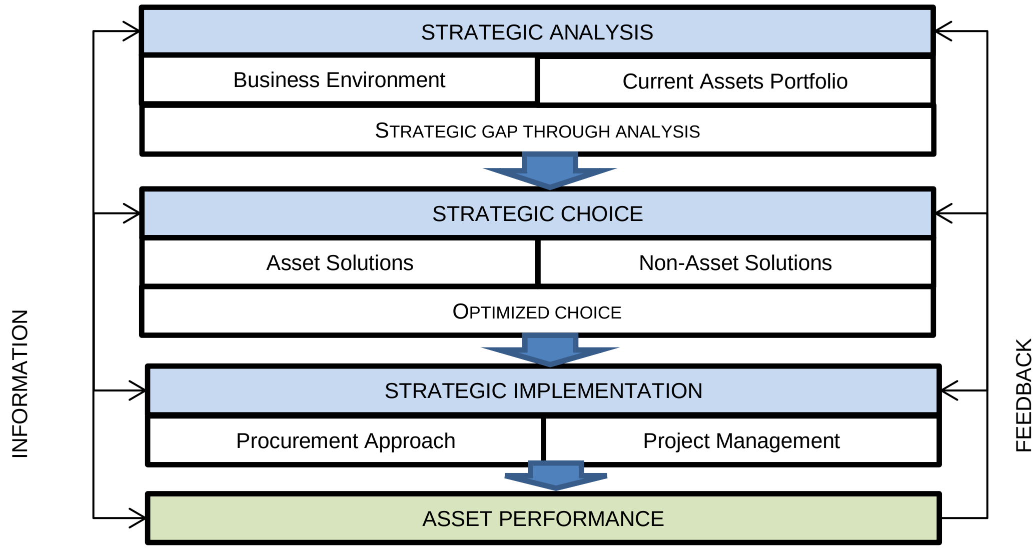


Figure 2.6: Generic asset management system process-flow

Source: (Too et al., 2006)

Another study, based on the similar concept of applying a generic strategic asset management system, suggested seven major components to represent the system (FHWA, 1999). These components are constrained by budgets and resource allocations, while key questions are generated to inform the whole process analytically. Figure 2.7 represents system components and Table 2.21 provides key questions in a generic asset management system. Their combined effect gives the design of the generic asset management system.

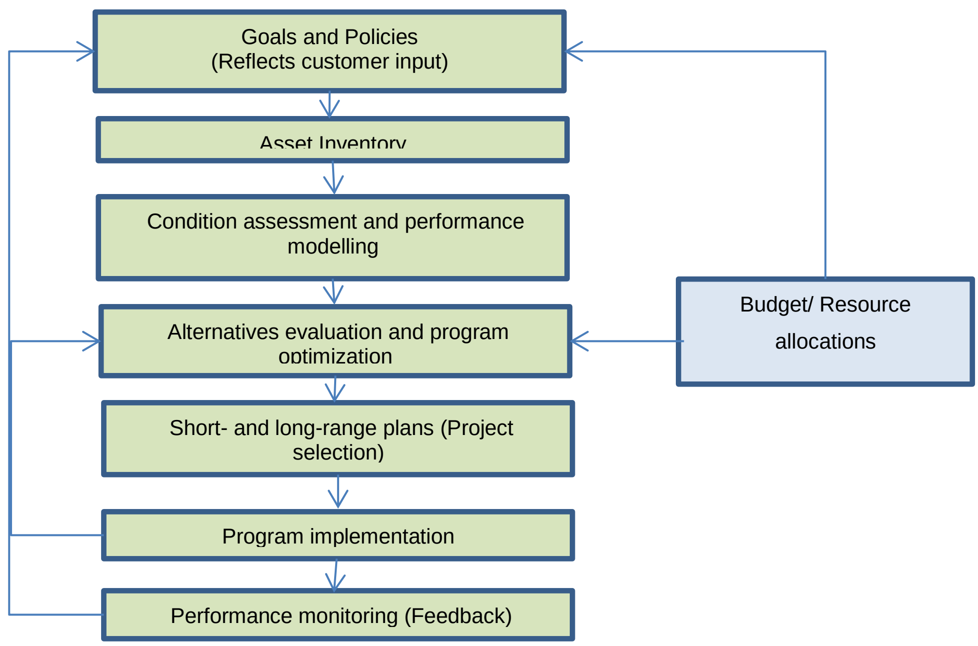


Figure 2.7: Generic asset management system: System components

Source: (FHWA, 1999)

Table 2.21: Generic asset management system: Key questions

Key Questions	
Question number	Question
1	What is our mission? What are our goals and policies?
2	What is included in our inventory of assets?
3	What is the value of our assets? What are their functions? What services do they provide?
4	What was the past condition and performance of our assets? What is the current and predicted future condition and performance of our assets?
5	How can we preserve, maintain, or improve our assets to ensure the maximum useful life and provide acceptable service to the public?
6	What resources are available? What is the budget level? What is the projected level of future funding?
7	What investment options may be identified within and among asset component classes? What are their associated costs and benefits?
8	Which option, or combination of options, is “optimal”?
9	What are the consequences of not maintaining our assets? How can we communicate the impact of the condition and performance of our assets on the system and end user?
10	How do we monitor the impact of our decisions? How do we adjust our decision-making framework when indicated?
11	* How can we best manage our assets in order to least inconvenience the motoring public when the repair or replace these facilities?

***= This is related to road assets but can be adjusted related to the specific infrastructure asset**

Source: (FHWA, 1999)

Bernhardt et al. (2003) have followed the same process shown in Figure 2.7, but they propose a simplified and more comprehensive framework (Figure 2.8). Simplification has been achieved by sub-dividing major components and then following a conceptual grouping of the sub-divisions. They have also mapped each component in the context of geotechnical assets (Table 2.22). Although the framework refers to geotechnical assets, most components are general to all assets, and only a few are specific to the selected asset (Table 2.22).

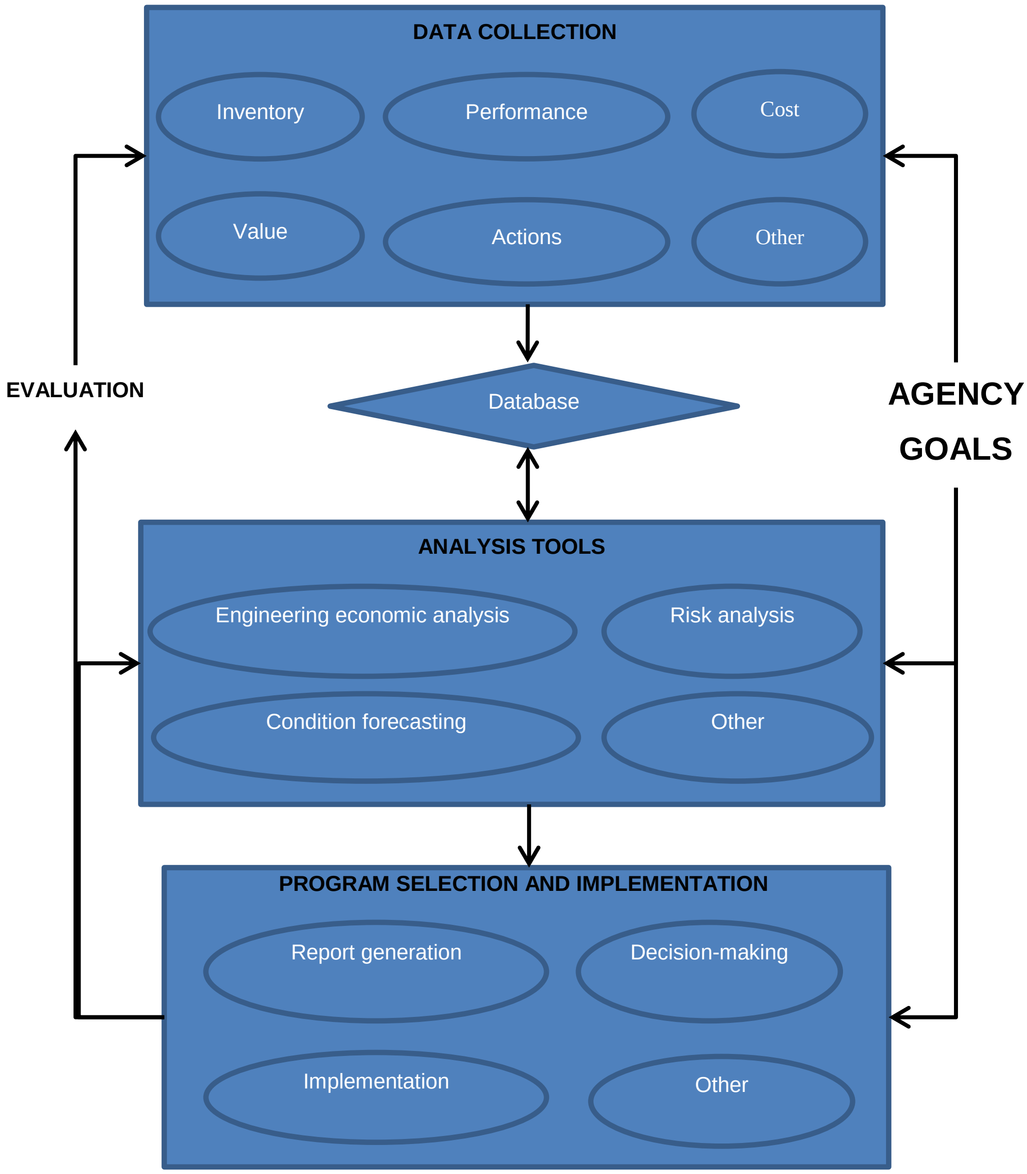


Figure 2.8: Asset management system components

Source: (Bernhardt et al., 2003)

Table 2.22: Mapping of geotechnical assets to asset management system components

System component	Description	Relevance to all assets
• Agency goals	Agency unlikely to have specific goals for geotechnical assets	General and specific
• Data Collection		
✓ Inventory	Location extent, height of embankment, soil properties, etc.	Specific
✓ Performance	Existing erosion, stability, etc.	Specific
✓ Cost	Maintenance budgets, cost of maintenance actions, etc.	General
✓ Value	Several options available; replacement cost may be most appropriate	General
✓ Actions	No action, monitor, temporary repair, permanent repair, etc.	General
✓ Other	Impacts of failure (safety and mobility), etc.	General and specific
• Analysis tools		
✓ Economic analysis	Calculate life-cycle costs to compare impacts of various maintenance and repair options, etc.	General
✓ Risk analysis	Evaluate risk of repair alternatives as well as risk of no repair	General
✓ Condition forecasting	Predict future condition of slope, embankment, etc., based on current and historical information, etc.	Process is similar in general but condition description can be varied
✓ Other	Calculate level of hazard and factors of safety, etc.	General and specific
• Program selection and implementation		
✓ Report generation	Tables, graphs, charts, etc.	General
✓ Decision-making	Compare costs, benefits, and risks of alternatives under different budget scenarios and choose course of action	General
✓ Implementation	Allocate resources and conduct projects	General
✓ Other	Suggest modifications to budget to achieve performance objectives	General and specific
• Evaluation	Evaluate whether data and analysis tools are providing useful information and whether goals are being met	General

Source: (Bernhardt et al., 2003)

2.6 Decision-making methods

2.6.1 Background

Decision-making plays a key role in the building management models and asset management systems which were discussed in the previous sections. Hence, it is vital to understand the term "decision-making" and explore suitable approaches to decision-making in the present research context.

2.6.2 Review of decision-making

(Harris, 2012) has defined decision-making in two different contexts: study and process. In the study context,

> *Decision-making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker.*

He explains further;

> *Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that (1) has the highest probability of success or effectiveness and (2) best fits with our goals, desires, lifestyle, values, and so on. The two important ideas here are that first, there must be some genuine alternatives to choose from among. Note that "Do it" or "Don't do it" does not qualify as a set of alternatives. Only "Do this" or "Do something else" really qualifies. Second, every decision must be made in the light of some standard of judgment. This standard usually gets expressed in the form of criteria, which reflect the values and preferences of the decision-maker. These values and preferences are often influenced by corporate rules or culture, law, best practices, and so forth.*

His second definition in the context of process suggests that

> *Decision-making is the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them.*

Here, he stresses the information-gathering function of decision-making. He further considers that decisions imply uncertainty, which can only be reduced but not eliminated. In his words:

> *Very few decisions are made with absolute certainty because complete knowledge about all the alternatives is seldom possible. Thus, every decision involves a certain amount of risk. If there is no uncertainty, you do not have a decision; you have an algorithm--a set of steps or a recipe that is followed to bring about a fixed result.*

He also categorises decisions. They are:

- **Decisions whether-** Type of yes/no, either/or decision-making that comes with the selection of an alternative. Pro and con analysis can be used in making such decisions
- **Decisions which-** Typical decisions of choosing between one or more alternatives from among a set of possibilities
- **Contingent decisions-** Decisions which are contingent on the right conditions
- **Contingent alternatives-** Decisions which are contingent on two or more choices of action, one of which will be taken when the appropriate trigger occurs

The general decision-making process has been identified as being comprised of eight major steps (Baker et al., 2002). They are:

Step 1: Define the problem

Step 2: Determine requirements

Step 3: Establish goals

Step 4: Identify alternatives

Step 5: Define criteria

Step 6: Select a decision-making tool

Step 7: Evaluate alternatives against criteria

Step 8: Validate solutions against problem statement

According to this process, identifying alternatives and defining criteria depends on the goals and alternatives of the case of the decision problem. Hence, cases can be different and be equipped with single criteria or multiple criteria. The present research problem involves many assessments, which naturally give rise to multiple criteria. Hence, the selection of decision-making methods is concerned with techniques of working with multiple criteria. Multiple attribute decision-making (MADM) is a widely used system, and therefore it is reviewed here. There are several types of MADM methods in practice, and a taxonomy has been developed by Yoon and Hwang (1995). The bases for the design of the taxonomy were: 1) type of information from Decision-Making and 2) salient feature of information (Figure 2.9).

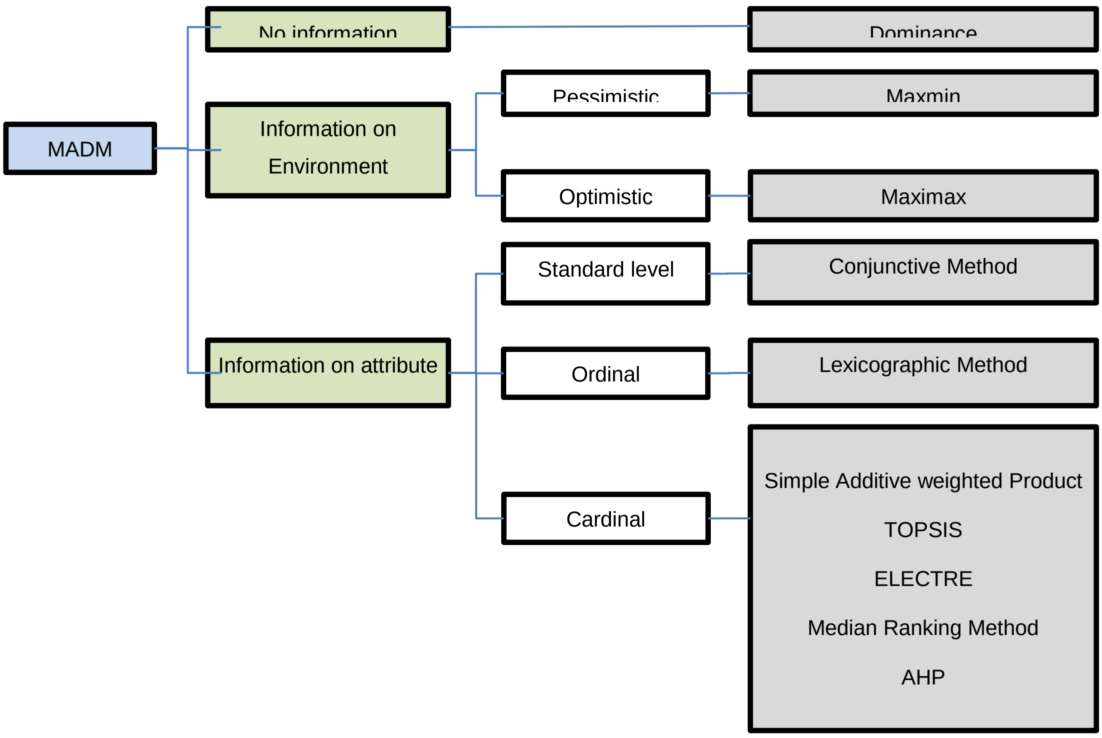


Figure 2.9: Taxonomy of MADM methods

Source: (Yoon and Hwang, 1995)

Attributes can be regarded as part of the criterion (Fülöp, 2005) and MADM can be regarded as a branch of the field of multiple criteria decision-making (MCDM) (Yoon and Hwang, 1995). Additional to MADM, MCDM includes multiple objective decision-making (MODM), which is used for problems exposed to a set of conflicting objectives for designing the best alternative (Hwang et al., 1993). The present research is assumed to lack situations leading to MODM. Therefore, attributes and criteria can be taken as synonymous, while MADM and MCDM can be represented as one system, MADM, which will be considered henceforth.

Problems involving a number of finite criteria and alternatives which can be expressed explicitly are said to require MADM (Fülöp, 2005). Apart from these two characteristics, Yoon and Hwang (1995) identified three more characteristics in such problems, regardless of their diversity: each attribute has different units of measurement (incommensurable units); incorporation of attribute weights; and concise representation of the problem with a decision matrix. Distilled to the essence of problem-solving, the generation of attributes is the initial task and the key role in the process. Keeney and Raiffa (1976) prefaced attribute generation with the need to include the following properties:

- Completeness
- Operational
- Decomposable
- Non-redundancy
- Minimum size

In general, the whole conceptual process of MADM can be summarised as follows(Dubois and Prade, 1980, Tzeng and Huang, 2011):

- Step 1: Define the nature of the problem
- Step 2: Construct a hierarchy system for its evaluation (Figure 2.10)
- Step 3: Select the appropriate evaluation model
- Step 4: Obtain the relative weights and performance score of each attribute with respect to each alternative
- Step 5: Determine the best alternative according to the synthetic utility values, which are the aggregation value of relative weights, and performance scores corresponding to alternatives

They have also proposed an additional step for situations where the overall scores of the alternatives are fuzzy. The step outranks the alternatives referring to their synthetic fuzzy utility values from step 5.

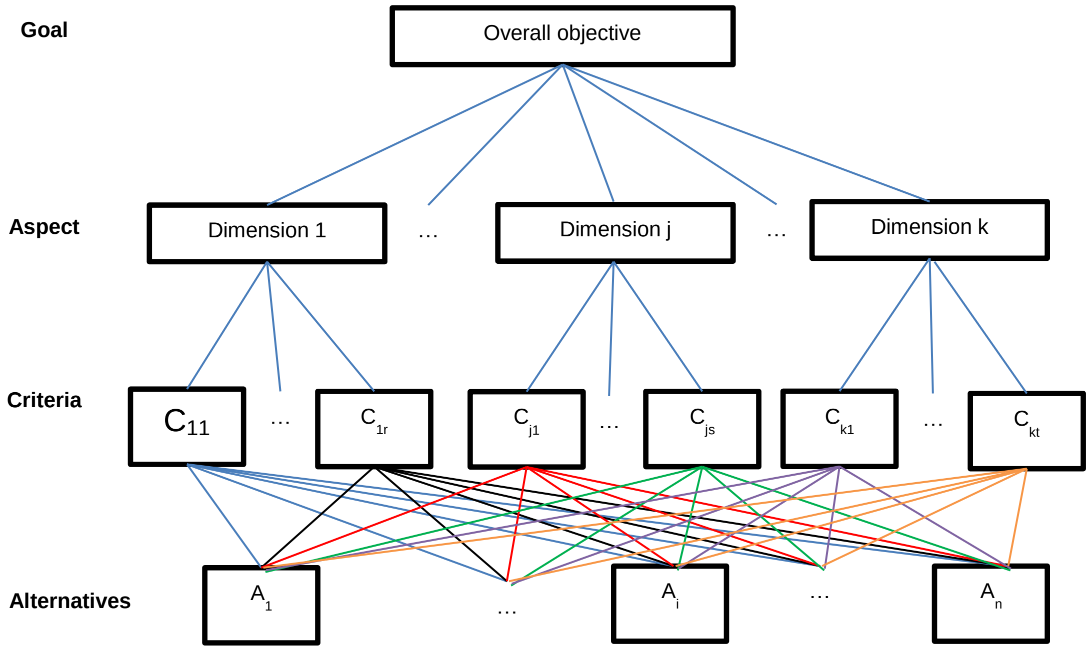


Figure 2.10: Hierarchical system for MADM

Source: (Tzeng and Huang, 2011)

2.7 Analytical hierarchical process (AHP)

2.7.1 Concept of AHP

AHP is a widely-used MADM method which can be used with problems involving qualitative data. Saaty (1980) invented the method for complex problems by understanding the problem through a hierarchical view. Furthermore, he introduced a table which enables the decision-maker to make the choice between two elements (normally attributes) by comparing pair-wise both qualitatively and quantitatively. Table 2.23 shows Saaty's table, in which a nine point intensity scale is used to express important classifications in linguistic terms.

Table 2.23: Saaty's pair-wise comparison table

Scale	Linguistic definition
1	Equally importance of both elements
3	Moderate importance of one element over another
5	Strong importance of one element over another
7	Very strong importance of one element over another
9	Absolute importance of one element over another
2,4,6,8	Intermediate values

Source: (Saaty, 1980, Saaty, 1990)

The application of AHP can be identified in three stages according to the layout of the process. They are;

- Hierarchic design
- Capture of pair-wise comparison data
- Performance aggregation through analysis

Problem identification through a multi-level structure is very important in the hierarchic design. The structure spreads commonly between the first level, which is the focus or objective of the application, and the last level, which are the alternatives. The objective can be captured by different aspects, which appears to be the better approach for the second level. Succeeding levels can be formed by the required criteria to fulfil aspects and similarly sub-criteria to criteria and so on. The remaining level after this process is connected to alternatives appropriately.

Pair-wise comparison normally starts from the last level and is applied to alternatives. The pair-wise comparison of alternatives will be acquired with respect to the immediate component (sub-criteria) connected with alternatives. The components of any bottom level will be pair-wise compared with the immediate component at their top level. This will continue until the second level, which reflects the objective through their pair-wise comparison.

Saaty (1980) developed a method to calculate priority levels or weightings of the relevant elements based on their pair-wise comparison data. Tzeng and Huang (2011) call this method the "Eigen value method" whereas Yoon and Hwang (1995) call it the "Hierarchical SAW method". An example is provided to explain the calculation process applied in AHP. For the example, n number of criteria is considered and compared pair-wise. Hence, a matrix, say P, can be formed using the pair-wise comparison data shown in Equation 2.3. Reciprocal values are used when the direction of the comparison is changed in the elements.

$$P = \begin{bmatrix} 1 & P_{12} & P_{13} & \cdots & \cdots & P_{1n} \\ 1/P_{12} & 1 & P_{23} & \cdots & \cdots & P_{2n} \\ 1/P_{13} & 1/P_{23} & 1 & \cdots & \cdots & P_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & 1 & \vdots \\ 1/P_{1n} & 1/P_{2n} & 1/P_{3n} & \cdots & \cdots & 1 \end{bmatrix}$$

.................Equation 2.3

Afterwards, normalisation is applied, and a normalised matrix can be derived. Let Wr be the weighting of the criterion r, then Wr is given by the following equation:

$$Wr= \frac{X_r}{\sum_{r=1}^{r=n} X_r} \quad \text{where} \quad X_r= \sum_{j=1}^{n} \frac{P_{rj}}{\sum_{i=1}^{i=n} P_{ij}}$$

Where; r=1, 2, 3… n

j= 1, 2, 3… n

i= 1, 2, 3… n

.................Equation 2.4

Hence, weighting values for all criteria can be calculated and a weighting matrix, W, is formed accordingly (Equation 2.5).

$$W = \begin{bmatrix} W1 \\ W2 \\ \vdots \\ \vdots \\ \vdots \\ Wn \end{bmatrix}$$

.................Equation 2.5

The final stage of AHP is the aggregation of these weightings or priority levels to obtain the priority level of alternatives for the objective of the problem. An example is considered to explain the phenomenon clearly. The problem has a three-level hierarchical flow which starts from the goal and follows through “n” number of criteria (C) to acquire “m” number of alternatives (A). The way the aggregation occurs can be shown as a multiplication of two matrices;

$$\begin{bmatrix} W_{A1C1} & W_{A1C2} & \cdots & \cdots & W_{A1Cn} \\ W_{A2C1} & W_{A2C2} & \cdots & \cdots & W_{A2Cn} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \ddots & \vdots \\ W_{AmC1} & W_{AmC2} & \cdots & \cdots & W_{AmCn} \end{bmatrix} \times \begin{bmatrix} W_{C1} \\ W_{C2} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ W_{Cn} \end{bmatrix} = \begin{bmatrix} W_{A1} \\ W_{A2} \\ \vdots \\ \vdots \\ W_{Am} \end{bmatrix}$$

................Equation 2.6

In decision-making problems it may be important to know how good our consistency is, because we may not want the decision to be based on judgements that have such low consistency that they appear to be random (Saaty, 1990).

In this regard, a certain degree of consistency is vital in pair-wise comparison data as it reflects the validity of the final decision. AHP addresses the issue by introducing a consistency ratio (CR) to measure the overall consistency of judgements. The CR (Equation 2.7) is derived by dividing the consistency index (CI) by a random consistency value (R). The value of the consistency ratio should be below or equal to 10 per cent (0.1) in order to keep the judgements consistent (Saaty, 1990).

$$CR=\frac{CI}{R}\leq 0.1$$

................Equation 2.7

R values vary according to the matrix size, which can be obtained according to Table 2.24. Maximum Eigen value or Lamda max (λ_{max}) is used to find the CI, which can be calculated from Equation 2.8 as follows;

$CI=\frac{\lambda max-n}{n-1}$ Where n is the size of matrix

.................Equation 2.8

Table 2.24: Random consistency values according to the size of matrix

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: (Saaty, 1990)

The calculation of λ_{max} for the previous example can be explained in the following steps;

- Let R matrix be the multiplication of P matrix (Equation 2.3) and W matrix (Equation 2.5), then R can be obtained from Equation 2.9.

$$[R]=\begin{bmatrix} 1 & P_{12} & P_{13} & \cdots & \cdots & P_{1n} \\ 1/P_{12} & 1 & P_{23} & \cdots & \cdots & P_{2n} \\ 1/P_{13} & 1/P_{23} & 1 & \cdots & \cdots & P_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & 1 & \vdots \\ 1/P_{1n} & 1/P_{2n} & 1/P_{3n} & \cdots & \cdots & 1 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ \vdots \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} R_{11} \\ R_{21} \\ R_{31} \\ \vdots \\ \vdots \\ R_{n1} \end{bmatrix}$$

.................Equation 2.9

- λ_{max} is given by Equation 2.10.

$$\lambda_{max}= \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n}$$

.................Equation 2.10

In contrast to Saaty‘s (1980) threshold of CR for being consistent with data, Pedrycz and Gomide (2007) proposed a threshold by manipulating CI. They maintained a superimposed value of 0.1 for CI index and stated that the experiment may need to be repeated if its CI index exceeds 0.1.

Although Saaty’s AHP is an advanced technique for problems with qualitative data and has been extensively applied to such problems, Buckley (1985) identified a shortcoming attributed to subjectivity and uncertainty, due to the single numbers used for pair-wise comparison. Buckley (1985) proposed a solution assigning a range of values for pair-wise comparison by utilising fuzzy logic. His proposal was the result of different techniques for AHP, commonly called fuzzy AHP methods. In each method, the table template for pair-wise comparison data is similar (Table 2.25). The following methods are more common in fuzzy AHP methods (Chen et al., 1992, Tzeng and Huang, 2011);

- Geometric mean method
- Linear programming method
- Fuzzy Lambda Max method

Table 2.25: The pair-wise comparison of linguistic variables using fuzzy numbers

Intensity of Fuzzy scale	Definition of linguistic variables	Fuzzy number	User defined
$\tilde{1}$	Similar importance	(L, M, U)	(_, 1, _)
$\tilde{3}$	Moderate importance	(L, M, U)	(_, 3, _)
$\tilde{5}$	Intense importance	(L, M, U)	(_, 5, _)
$\tilde{7}$	Demonstrated importance	(L, M, U)	(_, 7, _)
$\tilde{9}$	Extreme importance	(L, M, U)	(_, 9, _)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	Intermediate values	(L, M, U)	(_, _, _)

Source: (Tzeng and Huang, 2011)

2.7.2 AHP by application

The wide utilisation of AHP in numerous problem applications can be seen in a large number of related research reports. The applications are not limited to one area but cover diverse areas. According to Zahedi (1986), the number of areas exceeds 25 broad and specific areas. This highlights the power of AHP in problem-solving and decision-making.

Saaty (1990) showcases how AHP has been involved in problem-solving, providing a great range of cases of applications. His first example comes from politics, when US president Carter had to make a decision whether to send troops on a mission to rescue 53 American hostages from Teheran, where they had been held since early November 1979. Different levels of hierarchy were used in the problem, in which the first represented the likelihood of success of the project. Then it followed through different intermediate levels up to the last level which indicated the options whether to send or not send the troops. Seven people participated in giving pair-wise comparison data. Other examples he uses to showcase the importance of AHP are as follows;

- Determining consumer preference
- Estimating the economy’s impact on sales
- Selecting a portfolio

The AHP-based approach was used by Al Khali (2002) to select the most appropriate method for project delivery. The goal of the study was to allow project owners to decide the best project delivery method out of three different alternatives. He introduced a mathematical approach to evaluate the best method by using available specialized software or a spread sheet program.

Wei et al. (2005) used AHP in a systematic review of enterprise resource planning (ERP) to find the most suitable ERP system. Firstly, the authors developed a fundamental objective hierarchy system based on the fundamental idea of how to select the most suitable ERP system, and secondly, the means-objective network according to the established hierarchy. They carried out a factor analysis of the means-objective network and found major factors in different levels which ultimately influence the selection of the ERP system. The addition of alternative systems to the established hierarchy was the last task for the evaluation process. Depending on the highest value obtained for alternative systems, the most suitable system can be selected from Wei et al.’s (2005) approach.

Zhang and Zou (2007) applied AHP in order to assess the risks in joint venture (JV) projects in China with the use of expert knowledge. Their method was not just to apply AHP to identify the best alternative and then to make the decision, which was the primary focus of AHP as Saaty (1980) proposed. In contrast, they kept their objective to measure the risk condition of JV projects, which was at the first level of their hierarchy. For the next levels, they identified three major risk groups affecting the risk condition and each risk group depended on several risk factors. Hence, their evaluation started with risk factors and finished with the risk condition of the project. In their evaluation, weighting represented the priority level or significance of the attribute in the context of any project, whereas the performance or impact of an attribute was calculated according to a specific project. Pair-wise comparison data of five experts was used to calculate weightings individually and the average was kept as the weighting in terms of the group's decision. The SAW method was adopted to evaluate the aggregate value out of the values of weighting and performance. They exploited fuzzy logic in order to minimise subjectivity by measuring the performance with assigned numbers for linguistic expressions of impact levels.

Kahrman et al. (2003) used the fuzzy AHP approach to select the best facility for a new factory for a Turkish motor company out of three alternative locations. The best facility was selected on the basis of four criteria: environmental regulation (ER); host community (HC); competitive advantage (CA); and political risk (PR). The criteria with themselves and also with alternatives (Istanbul, Ankara, and Izmir) were compared using compromised decisive data of three members of the decision-making group. The method applied in the problem was an extended analysis of fuzzy AHP, which found Izmir to be the best selection.

The authors continued their interest in the method of extent analysis of AHP by incorporating the method in another application(Kahraman et al., 2004). This time it was to find the best catering service while providing the most customer satisfaction. In this case, three catering firms, namely Durusu, Mertol and Afiyetle, were considered and the problem was identified using a four-level hierarchy. Five experts from the Turkish Chamber of Food Engineers provided pair-wise comparison preferences for all attributes pertaining to the evaluation of the best catering company. Afiyette scored a very high priority level of 0.69 out of 1, and hence it was the recommended catering firm for the large textile company.

2.8 Artificial intelligence applications

2.8.1 Background

The purpose of artificial intelligence (AI) applications is to capture and reason about human knowledge, which is imprecise in nature (Yen and Langari, 1999). As a result, that type of intelligence is embedded in machines (Negnevitsky, 2011) and utilised to perform different tasks, otherwise the performance would be very complex and time-consuming if only humans were involved. Currently, it has been extended to different intelligent systems without changing the basic idea adopted early in AI development. That basic idea was that “an intelligent system for performing a specific task (a diagnosis) in a problem domain (lung diseases) can often benefit from knowledge about the problem domain” (Yen and Langari, 1999). The systems currently using AI applications can be summarized as follows (McDulling, 2006, Negnevitsky, 2011):

- Rule-based expert systems
- Fuzzy logic systems
- Frame-based expert systems
- Artificial neural networks (ANN)
- Genetic algorithms (evolutionary computation)
- Hybrid intelligent systems:
  - ✓ Neural expert systems
  - ✓ Neuro-fuzzy systems
  - ✓ Adaptive neuro-fuzzy inference system (ANFIS)
  - ✓ Evolutionary neural networks, and
  - ✓ Fuzzy evolutionary systems

The crux of the current research problem lies mainly in fuzzy logic systems, ANN and neuro-fuzzy systems in the quest for appropriate research methods. Therefore, they are discussed in the following section.

2.8.2 Fuzzy logic systems

FUZZY LOGIC

Basic probability theory may be the first mathematical approach to deal with uncertainty related problems (it was formulated in the 17th century (Negnevitsky, 2011)). Those applications dealt with stochastic uncertainty, for which uncertainty lay only in relation to the occurrence of a certain event of the selected variable or item, not the selected variable (Von Altrock, 1995). Two classical examples for dealing with stochastic uncertainty can be explained using a coin (item) and a dice (item). For a coin, the probability of obtaining heads on tossing is an event that is the only area uncertainty involved, but not the considered variable (heads). In contrast, for a dice, the probability of obtaining no 2 on throwing is an uncertain event, but never the numbers 1, 2, 3, 4, 5 and 6 of the dice.

Lexical uncertainty, which is the other uncertainty class, starts at the very beginning when variables are defined. For example, in selecting tall men out of a given group of people, “tall men” shows lexical uncertainty. Tall men are not precisely defined for all situations like the numbers on a dice. The meaning varies depending on the context and the background of the situation. Likewise, humans use subjective categories for criteria such as height, temperature, weight and so on in order to identify things in the real world by degree. Therefore, probability theory cannot be applied to deal with these situations because its axioms are not compatible with these subjective categories in human decision-making processes(Von Altrock, 1995).

Fuzzy logic has been developed to implement human logic, which comes through subjective categories. It has also been used in mathematical models for engineering solutions of such decision-making problems(Von Altrock, 1995). Fuzzy logic is mainly based on fuzzy sets, which are classes with imprecise boundaries. Hence, in a broad sense, fuzzy logic is a representation of theories and technologies employed with fuzzy sets (Yen and Langari, 1999). Fuzzy sets are completely different to crisp (classical) sets in their configuration. A crisp set carries the firm idea that only two opportunities exist, whether the considered items belong to the set or not. In contrast, considered items are partially connected to a fuzzy set through the term called membership. Fuzzy sets, basic operations of fuzzy sets and the basic process of fuzzy logic inference systems are discussed in some detail in the next sub-section.

BASIC CONCEPTS OF FUZZY LOGIC

Fuzzy sets

According to Yen and Langari (1999):

> *A Fuzzy set is a set with a smooth boundary. Fuzzy set theory generalizes classical set theory to allow partial membership. The best way to introduce fuzzy sets is to start with a limitation of classical sets. A set in a classical set theory always has a sharp boundary because membership in a set is a black and white concept- an object either completely belongs to the set or does not belong at all.*

This can be shown mathematically;

If U is the universe of discourse and x represents its elements, then the crisp set A of U or characteristic function of A is defined as $f_A(x)$:

$U \rightarrow (0,1)$

And

$$f_A(x) = \begin{cases} 1, & \text{if } x \in A \\ 0, & \text{if } x \notin A \end{cases}$$

.................Equation 2.11

In the Fuzzy theory, a fuzzy set A is a subset of the universe of discourse (U) is defined by a membership function (μA) where;

x represent elements of U

$\therefore \quad x \in U \quad$ and $\quad A \subset U$

Also $\mu_A(x) \rightarrow [0, 1]$

Thus, when

$\mu_A(x) = 1$ Then; x is totally in A

$\mu_A(x) = 0$ Then; x is not in A

$0 < \mu_A(x) < 1$ Then; x is partially in A

Hence, Fuzzy set theory can be shown in one mathematical expression as in the following equation (Equation 2.12).

$A = \{(x, \mu_A(x) / \quad x \in U, \quad A \subset U \ \& \quad \mu_A(x) \rightarrow [0, 1] \}$

.................Equation 2.12

Basic operations of fuzzy sets

Union, intersection and complement applied in classical sets can also be utilized in fuzzy sets. Their functions are very similar to the logic used in classical sets. Hence, union, intersection and complement sets in fuzzy logic follow disjunction, conjunction and negation in classical logic. Disjunction, conjunction and complement are illustrated in mathematical form in Equations 2.13 to 2.15 respectively (Yen and Langari, 1999).

$\mu_{A \cup B}(x) = \max\{\mu_A(x), \mu_B(x)\}$

.................Equation 2.13

$\mu_{A \cap B}(x) = \min\{\mu_A(x), \mu_B(x)\}$

.................Equation 2.14

$\mu_{A^c}(x) = 1 - \mu_A(x)$

.................Equation 2.15

Source: (Yen and Langari, 1999)

Basic process of fuzzy inference systems

According to Yen and Langari (1999), the core technique of fuzzy logic is based on four basics:

- Fuzzy sets are sets with smooth boundaries
- Linguistic variables are variables whose values are both qualitatively and quantitatively described by a fuzzy set
- Possibility distributions are constraints on the value of a linguistic variable imposed by a fuzzy set
- Fuzzy if-then rules are a knowledge representation scheme for describing a functional mapping or a logic formula that generalizes an implication in two-valued logic

The first three concepts are reflected in the idea of "Fuzzification" given by Nagnevisky (2011), which is the process up to rule evaluation in a Fuzzy inference system. According to this author, a fuzzy inference system is a process of mapping from a given input to an output, using the theory of fuzzy sets. He has further identified it as following four steps: fuzzification; rule evaluation; aggregation of the rule outputs and defuzzification. With a similar but slightly different idea, Yen and Langari (1999) explain the algorithm of fuzzy rule-based inference with three basic steps and an additional optional step: fuzzy matching; inference; combination and defuzzification (optional).

A fuzzy rule is the basic unit for capturing knowledge in many fuzzy systems. It has two components, namely antecedent and consequent. The antecedent starts with an if-part, which explains the combined structure of conditions of inputs, and a then-part shows the resulting consequent through the output. Conditions are normally combined in a rule connected with AND (conjunction), therefore, a conjunction operator is applied to find the resultant matching degree of conditions in the rule. In this regard, the most commonly used fuzzy conjunction operator is the min operator and the product operator (multiplication) is also used in some inference applications.

The next step is the inference, which is invoked for each of the relevant rules to produce a conclusion based on the matching degree out of related conditions. There are two methods: (1) the clipping method and (2) the scaling method, for generating such conclusions. Both methods suppress the membership function of the consequent. The clipping method cuts the top of the membership function and the rest of the membership function is the conclusion of the consequent. The scaling method preserves the same shape of the membership function of the consequent by obtaining proportional membership function as per its matching degree. However, the clipping method is more frequently used than the scaling method (Negnevitsky, 2011).

Combining Fuzzy conclusions or aggregating rule outputs is done by superimposing each output using the max disjunction operator. This gives the final result of the consequent in fuzzy form. Defuzzification is the step of converting this fuzzy form into a crisp form. There are two established defuzzification techniques: (1) the mean of maximum (MoM) method and (2) the centre of area (CoA), or the centroid method. According to Yen and Langari (1999):

> *The Mean of Maximum (MoM) defuzzification method calculates the average of those output values that have the highest possibility degrees. Suppose "y is A" is a Fuzzy conclusion can be defuzzified. We can express the MoM defuzzification method using the following formula:*

$$MoM(A)=\frac{\sum_{y^* \in P} y^*}{|P|}$$

.................Equation 2.16

where P is the set of output values y with highest possibility degree in A, That is;

$$P=\left\{ y^* \middle| \mu_A(y^*)=\sup_y \mu_A(y) \right\}$$

.................Equation 2.17

Source: (Yen and Langari, 1999)

The Centre-of-Area (CoA) method (also referred to as the centre of gravity, or centroid method in literature) is the most popular defuzzification technique. Unlike MoM, the CoA method takes into account the entire possibility distribution in calculating its representative point. The defuzzification method is similar to the formula for calculating the centre of gravity in physics, if we view $\mu_A(x)$ as the density of mass at x. Alternatively, we can view the CoA method as calculating a weighted average, where $\mu_A(x)$ serves as the weight for value x. If x is discrete, the defuzzification result of A is……(Yen and Langari, 1999):

$$CoA(A) = \frac{\sum_x \mu_A(x) \times x}{\sum_x \mu_A(x)}$$

................Equation 2.18

Similarly, if x is continuous, the result is:

$$CoA(A) = \frac{\int \mu_A(x)xdx}{\int \mu_A(x)dx}$$

................Equation 2.19

Source: (Yen and Langari, 1999)

McDulling (2006) states that

MoM computes a system output only for the term with the highest resulting degree of validity, such as pattern recognition applications. In decision support systems, the choice of defuzzification method depends on the context of the decision. CoA is used for quantitative decisions, such as budget allocation or project prioritization, while MoM is used for qualitative decisions, such as credit card fraud detection or credit worthiness evaluation.

Two particularly different fuzzy inference methods are used: (1) the Mamdani method and (2) the Takagi-Sugeno-Kang (TSK) method (Yen and Langari, 1999, Negnevitsky, 2011). Kosko's additive model (SAM) is also available, but its inference scheme is similar to the TSK method (Yen and Langari, 1999). The main difference in the two major types, Mamdani and Sugeno, is that the Sugeno method replaces the Fuzzy sets in the consequent (then-part) of the Mamdani rule with a linear equation of the input variables (Yen and Langari, 1999). As a result, the Sugeno method is more computationally efficient than the Mamdani method (Negnevitsky, 2011).The Sugeno method uses the weighted sum as the inference analogous to aggregating the conclusion of multiple rules into a final conclusion. Hence, this method is called an additive rule method. On the other hand, the Mamdani method combines the inference results of rules using super-imposition, not addition. Hence, it is a non-additive rule method. Having discussed fuzzy inference systems (FIS) throughout this section, a basic overview is shown in Figure 2.11.

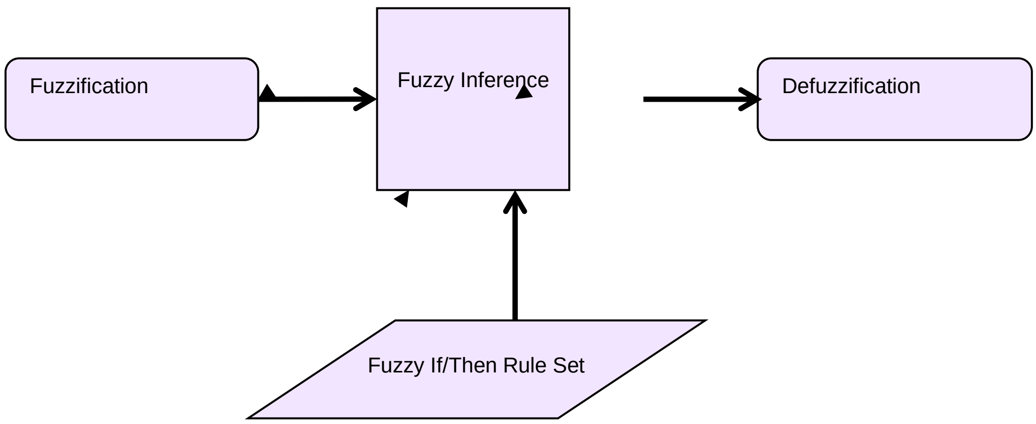


Figure 2.11: Basic overview of FIS

2.8.3 Artificial Neural Networks (ANN) systems

The principle of neural networks concerns the way the human brain performs with its densely interconnected set of nerve cells, called neurons (Negnevitsky, 2011). Neurons and their elements: soma, dendrites, axons and synapses are the structures forming the processing unit of the human brain. By means of this processing unit, the brain is able to perform diverse human functions even faster than the current advanced computers (Negnevitsky, 2011). Likewise, neural networks are computational models that consist of nodes, which are like neurons that are connected by links. Each node performs a simple operation to compute its output from its input, which is transmitted through links connected to other nodes (Yen and Langari, 1999).

One of the major features of a neural network is its learning capability. Different learning algorithms are available for the learning systems but one thing is common to all. Each system has the capacity to adjust the parameters in a neural network by allowing the network to learn to improve its performance of a given task (Yen and Langari, 1999). On the other hand, numerical weights are assigned to links, which act as the long term memory identical to the synapses in the human brain (Negnevitsky, 2011). Negnevitsky (2011) researched two systems; a biological neural network related to the human brain, and an artificial neural network related to artificial intelligence, and developed an analogy between the two systems as shown in the following table.

Table 2.26: Analogy between biological and artificial neural networks

Biological neural network	Artificial neural network
Soma	Neuron
Dendrite	Input
Axon	Output
Synapse	Weight

Source: (Negnevitsky, 2011)

The structure of a neural network can be represented by different layers organised with nodes. The first layer represents input signals and the last layer is for output signals, while intermediate layers are called hidden layers which are the interface between the first and last layers. The basic structure of a neural network can be represented schematically as in Figure 2.12. A simple computational configuration of a neuron is shown in Figure 2.13 and it can be mathematically explained as follows:

The weighted sum of all input signals= Propagation function= S_j can be computed by the following equation;

$$S_j = \sum_{i=1}^{k} W_{ij} \times X_i$$

.................Equation 2.20

In the next step, the sum calculated is fed to a pre-defined function, ∫, also called the activation function (typically a sigmoid function), to output signal of the node. Once the sum is fed to that function it gives the output signal, which is shown by X_j and it is calculated by the following equation:

$$X_j = \int (S_j) = \int \left[\sum_{i=1}^{k} W_{ij} \times X_i \right]$$

.................Equation 2.21

source: (Von Altrock, 1995, Yen and Langari, 1999)

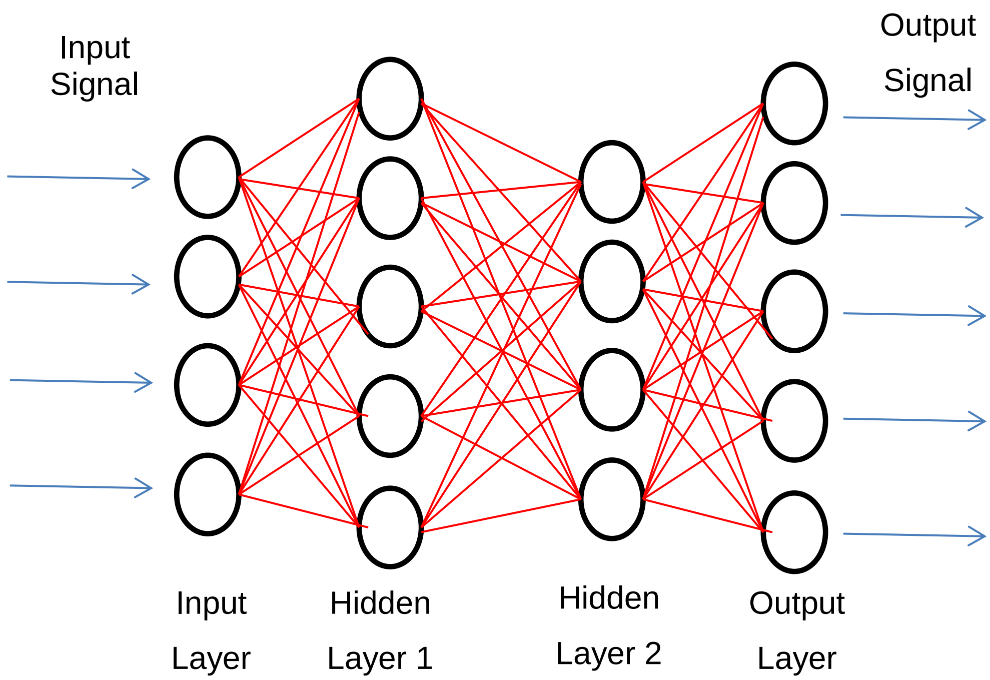


Figure 2.12: Basic Structure of a neural network

Source: (Von Altrock, 1995)

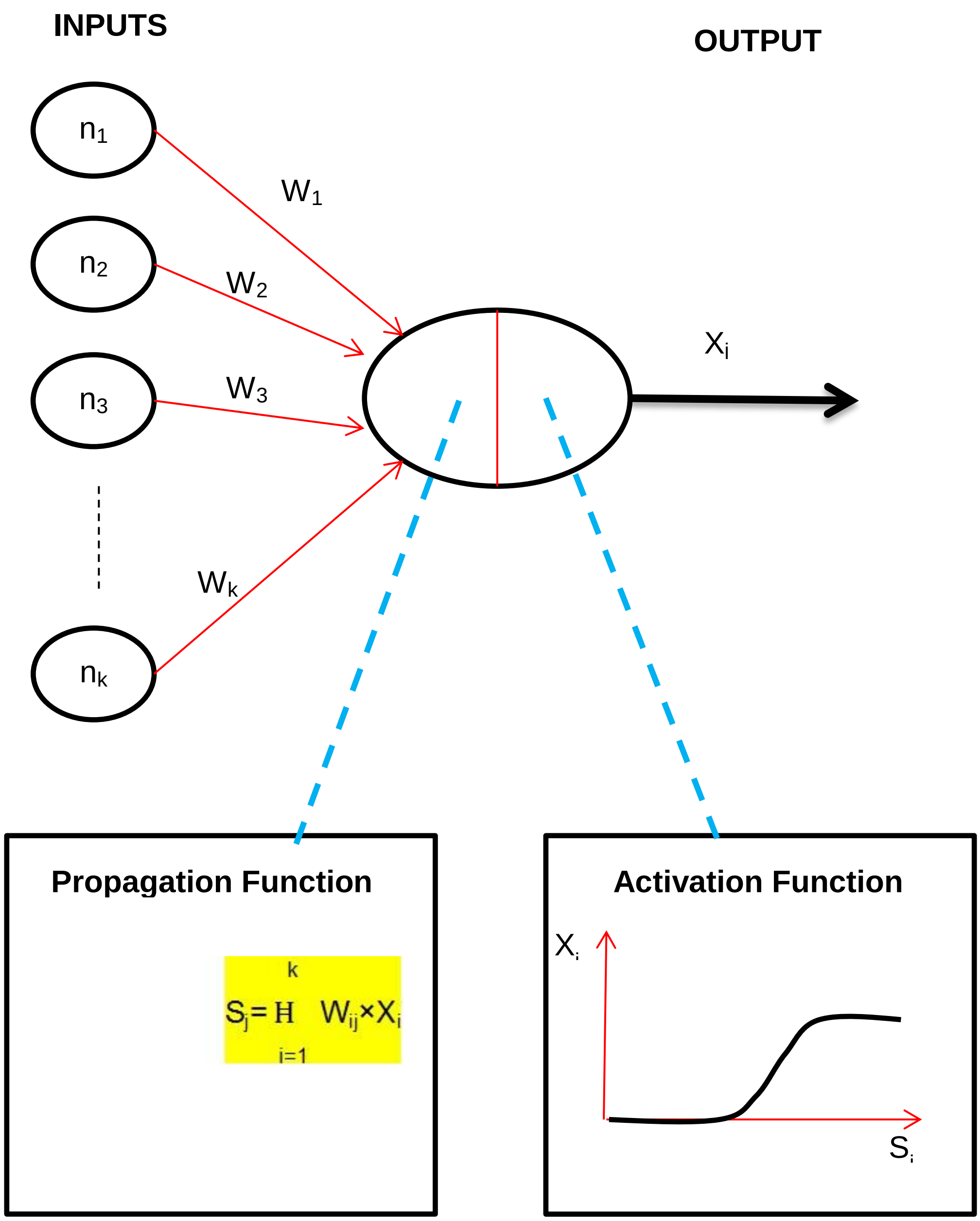


Figure 2.13: Basic computation of a neuron

Source: (Von Altrock, 1995, Yen and Langari, 1999)

2.8.4 Neuro-fuzzy systems

According to Yen and Langari (1999):

> *"Neural networks" can learn from data and feedback; however, understanding the knowledge or the pattern learned by the neural networks has been difficult. More specifically, it is difficult to develop an insight about the meaning associated with each neuron and each weight. Hence, neural networks are often viewed as a "black box" approach- we can understand what the box does, but not how it is done conceptually. In contrast, "Fuzzy rule-based models" are easy to comprehend because it uses linguistic terms and the structure of If-then rules. Unlike neural networks, fuzzy logic does not come with a learning algorithm.*

As shown above, there are strengths and weaknesses of both methods. The combination of these two techniques is a clever idea for delivering more sophisticated outcomes by combining the strengths and minimising the weaknesses of both methods.

> *A Neuro-fuzzy system can be loosely defined as a system that uses a combination of fuzzy logic and neural networks (Yen and Langari, 1999).*

Negnevitsky (2011) further explains a Neuro-fuzzy system in the following manner:

> *A Neuro-Fuzzy system is, in fact, a neural network that is functionally equivalent to a fuzzy inference model. It can be trained to develop if-then fuzzy rules and determine membership functions for input and output variables of the system. Expert knowledge can be easily incorporated into the structure of the Neuro-fuzzy system. At the same time,*

> *the connectionist structure avoids fuzzy interference, which entails a substantial computational burden.*

Following the idea of Neuro-fuzzy system, Von Altrock (1995) identifies five steps in developing a Neuro-fuzzy system:

Step 1: Obtain training data
Step 2: Create a fuzzy logic system
Step 3: Define the Neuro-fuzzy learning
Step 4: Training phase
Step 5: Optimization and verification

Particularly in Neuro-fuzzy system applications, the determination of the number of important fuzzy rules strikes a balance between reducing the fitting error and reducing the model complexity. In this case, orthogonal transformation methods are used to extract important fuzzy rules from a given rule base (Yen and Langari, 1999).

> *Unlike conventional methods where multiple iterations are usually required to find the "optimal" number of fuzzy rules, orthogonal transformation methods are a non-iterative procedure. They start with an oversized rule base and then remove redundant or less important fuzzy rules through a "one pass" operation.*

2.8.5 Applications using artificial intelligence systems (fuzzy logic systems, artificial neural networks and Neuro-fuzzy systems)

Jin and Doloi (2009) used fuzzy inference system (FIS) to model risk allocation in privately-financed infrastructure projects. Their FIS included six input variables: risk management (RM) routine; cooperation history; environmental uncertainty; RM commitment by public partners; RM commitment by private partners; and RM mechanism, in order to evaluate the output of the risk allocation strategy. All input variables and the output variable followed Gaussian membership functions varying across1 to 5 numbers in the variable axis. The membership functions of every input variable except the

RM routine were clarified by two linguistic terms, either low and high, or immature and mature. In contrast, the membership function of the output variable comprises three linguistic terms, of which 1 means ‘retain all’ while 3 and 5 represent ‘equally share’ and ‘transfer all’ respectively. The other input “RM routine” also follows the same numbers as in the output, but the linguistic terms are changed to low, medium and high. Five experts were invited to generate fuzzy if-then rules and eliciting the consenting opinions of the panel was done using the Delphi procedure. Finally, they developed a model to run their fuzzy inference system using Matlab software.

In another study, Bowles and Peldez (1995) developed a FIS model using three parameters: severity, frequency of occurrence, and detectability of an item failure, as input variables in order to assess the risk of failure. Different linguistic terms were applied to input and output variables and they varied in triangular and trapezoidal ways. A rule base was developed combining the expert knowledge and expertise with the rule development process of Fuzzy model. The min-max inference approach was used to find the conclusions of rules, whereas the weighted mean of maximum (WMoM) was the defuzzification method. Abdelgawad and Fayek (2010) conducted a very similar study, but their approach was slightly different, as they applied a combined FIS and Fuzzy AHP for failure mode and effect analysis (FMEA). They used Fuzzytech software in their programming and the results of case study data were presented to validate the concept.

Mao (1999) repeatedly applied FIS in his three-level hierarchical framework for estimating labour productivity. In accordance with the hierarchical process, labour productivity was in the last level, which was determined through three factors in the second level, namely design consequence, project consequence and activity consequence. Similarly, three of the factors were determined through other separate factors in the first level, such that, three design factors were combined to assess the design consequence, whereas four project factors and five activity factors were exploited to assess project consequence and activity consequence respectively. Therefore, Mao’s evaluation started from the first level and gradually followed until labour productivity was determined. In his FIS approach, he adopted triangular membership functions and expert opinion was utilised in the development of rules. Furthermore, he elicited relevant opinions through four bases: experience, common sense, publications and historical database. Finally he developed a computer program (FIFT.EXE) to run fuzzy inference operations and also for fine-tuning of fuzzy rules.

Having statistically analysed and identified 11 significant factors influencing the deterioration of bridges, Huang (2010) developed an artificial neural network (ANN) model to address the deterioration prediction of bridges. He developed the model in the form of a Matlab software program and data captured from one district in Wisconsin were applied to the model for learning purposes. The model was designed as a pattern classification problem, and he found that the developed model has the capacity to accurately predict the condition of bridge decks. Another study in which ANN was applied was for generating historical bridge condition ratings using limited bridge inspection records (Lee et al., 2008). Back-propagation feed-forward ANN was applied in their model following the training and testing stages. The training stage was to detect patterns of interest in the dataset, while additional patterns of the dataset, which were not fed into the network model, were the inputs for the testing stage to produce suitable outputs.

Boussbaine (2001) discussed modelling of construction project durations using a Neuro-fuzzy modelling approach. He outlined the significant sequential steps towards such a Neuro-fuzzy model. First they follow common FIS steps: defining inputs and out puts and their membership functions; mapping the input space to the output space by rules, up to the step of defuzzification of the output. Then back propagation is carried out to train and update weights associated with the generated rules, where the weights change through the learning process. The system has considerable accuracy of predictive power which can be enhanced through sequential procedures including optimisation, validation, set up and maintenance.

McDulling (2006) also used a Neuro-fuzzy model to obtain degradation rates for all conditions, assuming the building was initially at the selected condition. For example, if the selected condition was 1, then the degradation rate implied the remaining portion (x) of the condition 1 after one year. Accordingly (1-x) portion was the condition 2. These values were used to formulate a transition matrix, which was utilized to predict the service life of the building using a mathematical method called the Markov chain. Cheng et al (2008) also adopted a Neuro-fuzzy model to apply to decision-making in geotechnical engineering. In addition to the two AI techniques, these authors used a genetic algorithm to optimize the ability of the fuzzy neural network to overcome the bottleneck of fuzzy neural network application. They covered the application of the model in real decision-making problems using two case studies: the first was to estimate the construction duration of a slurry wall; the second was the selection of retaining wall construction method.

2.9 Condition monitoring of buildings

A combined system of condition assessment and performance monitoring is critical to any asset including buildings for the following reasons (IIMM, 2006);

- All management decisions regarding maintenance, rehabilitation and renewals are based on them
- It is the only reliable tool which can be engaged in the prediction of the remaining life of assets or their components
- A successful monitoring system has great potential for preventing unforeseen failures of assets

Having understood the importance of this system, IPWEA (2009) state the objective of a better condition assessment process as follows:

> *The objective of a condition assessment is to provide sufficient information on asset condition to allow informed strategic asset planning and management decisions to be made.*

To achieving this objective, IIMM (2006) recommend taking account of the following aspects during the process:

- Assessment standards

- Failure pattern
- Rating systems
- Condition rating outputs
- Condition monitoring approach

On the other hand, IPWEA (2009) state that in relation to buildings, that following factors are involved in condition assessment:

- Physical inspection of a building to assess the actual condition of the building and its building fabric (linings, finishes, and fixtures) and plant and equipment (heating, ventilation, air conditioning, fire protection, lifts, etc.), in comparison with the asset owner's 'inherent' or 'intuitively determined' condition standard and eventually, the organization's level of service standards or quality standards
- Identification of both short-term maintenance works and longer-term renewals or refurbishments required to bring the condition of the building fabric, plant and equipment up to, and maintain it at, the agreed condition standard
- Ranking of these maintenance works and longer term renewals in order of priority
- Determination of actions by the assessors to mitigate any immediate risk until remedial works (or other actions) can be taken to address problems

According to Uzarski and Burley (1997), routinely scheduled condition survey inspections are required for the planning of maintenance and repair of building components of a building. These authors also emphasise that these inspections need to be uniform and designed in a way to provide repeatable condition assessment results from different inspectors. Hence, condition rating systems play a vital role.

> The most commonly adopted condition rating system across many asset classes is the basic 1 to 5 where condition 1 is very good or as new and condition 5 is very poor and approaching the state of unserviceable. However, some organisations rate in reverse; 1 being very poor and 5 being very good. It is appropriate to use whichever

rating system works for particular organisation … there is no absolute right answer”(IPWEA, 2009).

Clear definitions correlated with condition grading are essential for condition inspectors, regardless of the rating scale they use. Several such condition rating scales incorporated with linguistic descriptions can be found in the literature. They are illustrated in Tables 2.27 to 2.29.

Table 2.27: Typical condition rating system (1 to 5) by IPWEA (2009)

Rating	Condition Rating Description
1-Excellent	Asset has no defects. Asset is as new
2-Good	Asset is functional and displays superficial defects only minor signs of deterioration to surface finishes; but does not require major maintenance; no major defects exist
3-Average	Asset is functional but shows signs of moderate wear and tear; deteriorated surfaces require attention; services are functional, but require attention; backlog maintenance work exists
4-Poor	Asset functionality is reduced. Asset has significant defects affecting major components deteriorated surfaces require significant attention; services are functional but failing often; significant backlog maintenance work exists
5-Failed	Asset is not functional. Asset has deteriorated badly; serious structural problems; general appearance is poor with eroded protective coatings; elements are broken, services are not performing; significant number of major defects exist

Source:(IPWEA, 2009)

Table 2.28: Condition rating system (1-5) adopted by Abbot et al (2007)

Rating	Condition Rating Description
1-Very Good	The component or building is either new or has recently been maintained, does not exhibit any signs of deterioration.
2-Good	The component or building exhibits superficial wear and tear, minor defects, minor signs of deterioration to surface finishes and requires maintenance/ servicing. It can be reinstated with routine scheduled or unscheduled maintenance/ servicing
3-Fair	Significant sections or component require repair, usually by a specialist. The component or building has been subjected to abnormal use or abuse, and its poor state of repair is beginning to affect surrounding elements.
4-Bad	Substantial sections or components have deteriorated badly, suffered structural damage or require renovations. There is a serious risk of imminent failure. The state of repair has a substantial impact on surrounding elements or creates a potential health or safety risk.
5-Very Bad	The component or building has failed, is not operational or deteriorated to the extent that does not justify repairs, but should rather be replaced. The condition of the element actively contributes to degradation of surrounding elements or creates a safety, health or life risk.

Source: (Abbott et al., 2007)

Table 2.29: Rating scale adopted by Maloney modelling

Rating	Condition Rating Description
0	A new asset or an asset recently rehabilitated back to new condition. (Score as 1 to avoid confusion in rating systems)
1	A near new asset with no visible signs of deterioration often moved to condition 1 based upon the time since construction rather than observed condition decline
2	An asset in excellent overall condition. There would be only very slight condition decline but it would be obvious that the asset was no longer in new condition
3	An asset in very good overall condition but with some early stages of deterioration evident, but the deterioration still minor in nature and causing no serviceability problems
4	An asset in good overall condition but with some obvious deterioration evident, serviceability would be impaired very slightly
5	An asset in fair overall condition deterioration in condition would be obvious and there would be some serviceability loss.
6	An asset in fair to poor overall condition. The condition deterioration would be quite obvious. Asset serviceability would now be affected and maintenance cost would be rising.
7	An asset in poor overall condition deterioration would be quite severe and would be starting to limit the serviceability of the asset. Maintenance cost would be high.
8	An asset in very poor overall condition with serviceability now being heavily impacted upon by the poor condition. Maintenance cost would be very high and the asset would at a point where it needed to be rehabilitated.
9	An asset in extremely poor condition with severe serviceability problems and needing rehabilitation immediately. Could also be a risk to remain in service
10	An asset that has failed is no longer serviceable and should not remain in service. There would be an extreme risk in leaving the asset in service

Source: (IPWEA, 2009)

The building hierarchy adopted by the organisation, as discussed in Section 2.10, allows the organisation to develop condition data at the lowest level of the hierarchy. Understanding of the condition data of other levels is essential for higher levels of strategic management plans such as: planning of building refurbishments, budgets, etc. and the maintenance and replacement plans of individual elements. Condition aggregation is a more viable solution which not only sets condition targets for assets, but also benchmarks the building stock (Straub, 2006).

Among the different approaches for condition aggregation, the simplest approach would be using an arithmetic mean of the conditions of components. The method, which assigns a weighting for each component and calculates the weighted aggregate condition of the immediate large element in the hierarchy, is a much better approach. However, the best way of assigning weightings for components is a challenge. Weightings are captured mainly based on the significant factor components exhibited by different aspects; cost, length, area, risk and so on. For this purpose, Uzarski and Burley (1997) give a convincing demonstration of assigning weightings in different scenarios in the hierarchy.

2.10 Building hierarchy systems

According to Uzarski and Burley (1997), a building system/component hierarchy is related to building systems and components and creates management units that can be readily inspected. They also report that it also identifies building elements requiring unique inspection techniques and other management attention. The International Infrastructure Management Manual (IIMM, 2006) explains the significance of having a hierarchy for all infrastructure assets as follows:

> *The information needs of the organisation vary throughout the management structure. At the workface, the key elements are operations, maintenance, and resource management at a component level. At higher management levels, this information needs to be aggregated to provide details on assets, facilities and (infrastructure) systems as a whole in terms of finance, strategic planning and policy.*

Based on Uzarski and Burley (1997) and IIMM (2006), it is obvious that having a comprehensive building hierarchy system and recording and maintaining data collection according to that hierarchy system have an immense impact on different tasks such as: service life prediction of buildings, maintenance and replacement planning, budget planning and so on.

Therefore, organisations apply different hierarchies for the effective achievement of the outcomes.

Firstly, IIMM (2006) suggests a general hierarchy for all infrastructure assets (Figure 2.15). It starts with the whole infrastructure asset and then breaks it down to a large unit of that whole asset (normally called a facility). Then it expands to the facility or service area of the selected facility and finally to the components functioning in the facility area. Sometimes, it can expand to sub-components of components. For example, water supply assets are the whole infrastructure asset, whereas a treatment plant is one facility in the water supply chain. Similarly, the intake system is one facility area in the context of a treatment plant, whereas the structure, pipes and valves are components belonging to the facility.

Different research studies have followed different building hierarchical systems. For example, the hierarchical systems adopted by Uzarski and Burley (1997) and IPWEA (2009) are shown in Figures 2.14 and 2.15. In addition, another hierarchy system followed by a local council in Victoria is shown (Figure 2.16) to showcase a hierarchical system used in practice. Currently, the hierarchical system (NAMS hierarchy) proposed by IPWEA (2009) is a standard for local councils in Australia due to its comprehensiveness; therefore its detailed component list attached and hierarchy is illustrated in Appendix A.

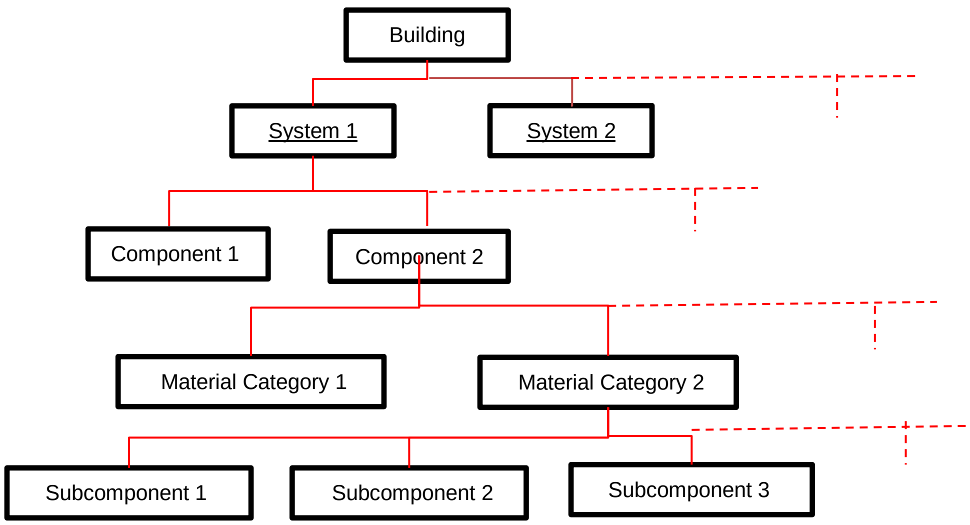


Figure 2.14: Building hierarchy adopted by Uzarski et al. (1997)

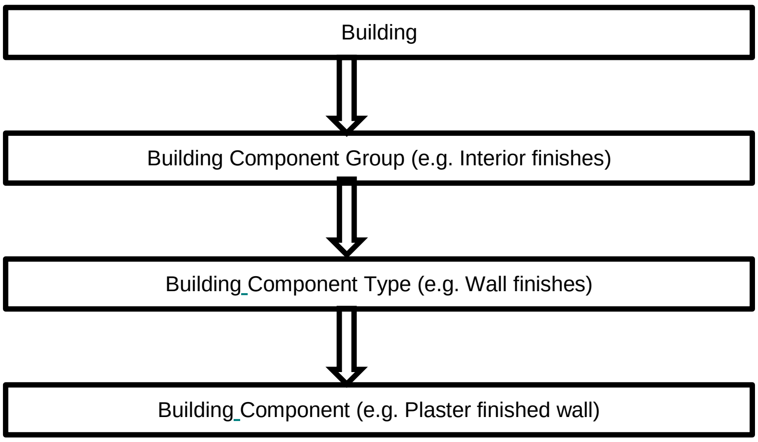


Figure 2.15: Building hierarchy adopted by IPWEA (2009)

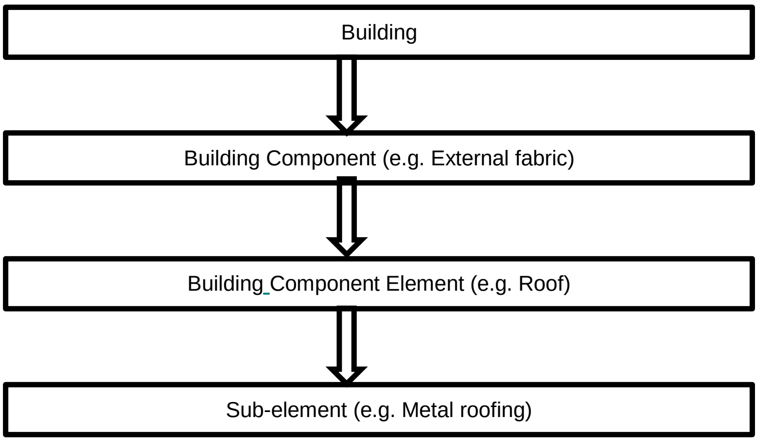


Figure 2.16: Building hierarchy adopted by a partner council

2.11 Deterioration prediction

2.11.1 Background

According to (Hovde and Moser, 2004):

> *Service life prediction of buildings or building elements, components or products can be both complex and time-consuming process. To date, the methods have not been developed into an exact science given the many different factors that must be considered that thereby make a thorough service life prediction an interdisciplinary activity. Service life prediction can be based on two different*

principal approaches: Deterministic approach and Probabilistic approach

In the context of bridges, Marcous et al. (2002b) found two unique models, stochastic and artificial intelligence, served for the probabilistic approach, while only deterministic models served for the deterministic approach. They state the suitability of those models, not only for bridges but also infrastructure assets, in another study (Morcous et al., 2002a). Table 2.30 shows the three model categories, including the specific techniques applied in each model and the specific methods relevant to each technique. Dasu and Johnson (2003) also characterize these models by the driving force of each model. According to these authors, statistical models and deterministic models are model-driven, whereas artificial intelligence models are data-driven. Moreover, experts decide the structures of each statistical and deterministic model, while the structures of artificial intelligence models are decided by the sample data.

Table 2.30: Categories of deterioration prediction models

Category	Technique	Method
Deterministic models	Straight-line extrapolation	—
	Regression models	Stepwise regression
		Linear regression
		Nonlinear regression
	Curve-fitting models	B-spline approximation
		Constrained least squares
Stochastic models	Simulation models	—
	Markovian models	Percentage prediction
		Expected-value method
		Poisson distribution
		Negative-binomial model
		Ordered-probit model
		Random-effects model
		Latent Markov-decision process
Artificial intelligence models	Artificial neural networks	—
	Case-based reasoning	—

Source: (Morcous et al., 2002b)

In their detailed analysis of the advantages and disadvantages of the three models, Morcous et al (2002b) identify some shortcomings of Markovian models. However, Markovian models can be seen as extensively applicable to infrastructure facilities to model their deterioration (Butt et al., 1991, Cesare et al., 1992, Baik et al., 2006, Micevski et al., 2002). These applications suggest that the Markov chain is the preferable method to predict the service life of infrastructure assets by simulating the transition of states (conditions) over time (McDulling, 2006, Morcous et al., 2002b). This is the main approach used in the parallel research on the deterioration prediction of community buildings (Mohseni, 2012). Hence, the next sub-section reviews the Markov process and its use in deterioration prediction.

2.11.2 Markov process

The Markov chain is the theory embedded in any Markov process application. It is often called the discrete time Markov chain because defined random variables (or states or conditions) are observed at discrete points in time. As stated above, the Markov chain can predict the future state of any condition, provided that transitional frequency of each condition is known. Hence, the transitional probability plays a key role in predictions using the Markov chain. When the transition probability is calculated, transition is assumed to occur from one state to another state during a selected fixed time interval. For example, if the probability of the transition from state i to state j occurring during a fixed time period (k) is known and given as P_{ij}, then Pij is called the transition probability of state i to state j at the time step k. Furthermore, if there are n number of states, the transition probability of each one state to another (during one time step k) can be shown by means of a n×n matrix (P=Transition probability matrix), and the matrix is shown as follows;

$$
P = \begin{array}{c} \\ (1) \\ (2) \\ \cdots \\ (i) \\ \cdots \\ (n) \end{array}
\begin{array}{c}
\begin{array}{cccccc} (1) & (2) & \cdots & (j) & \cdots & (n) \end{array} \\
\left| \begin{array}{cccccc}
P_{11} & P_{12} & \cdots & P_{1j} & \cdots & P_{1n} \\
P_{21} & P_{22} & \cdots & P_{2j} & \cdots & P_{2n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
P_{i1} & P_{i2} & & P_{ij} & \cdots & P_{in} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
P_{n1} & P_{n2} & \cdots & P_{nj} & \cdots & P_{nn}
\end{array} \right|
\end{array}
$$

................Equation 2.22

The probability values satisfy following conditions:

- $P_{ij} \geq 0$
- Better states fall into worse states over the time but not the other way around; therefore all values below the diagonal (from top left corner to bottom right corner) of the matrix are equal to zero
- For a given i; $\sum_{j=1}^{n} Pij=1$

Markov chain application starts mainly with this transition probability matrix and it needs some additional information to make future predictions. As the transition probability values are based on a selected fixed period interval, the availability of the percentage of (or probability of being in) each state initially must be included with the additional information. Assume initial state percentages are known. Then, it can be shown by one row matrix as follows:

$$C\,(0)= \begin{vmatrix} C_1^0 & C_2^0 & \dots & C_i^0 & \dots & C_n^0 \end{vmatrix}$$

.................Equation 2.23

where, C_i^0 is the percentage of (probability of being in) state i and C (0) is the initial system. After one interval, each state of the system starts to vary according to the transition probability matrix, which is given through a product of two matrices based on the Markov chain. If the system after one interval is depicted as C (1), then C (1) can be formulated by the product of Equations 2.22 and 2.23, which is shown by Equation 2.24.

$$C\,(1)= \begin{vmatrix} C_1^0 & C_2^0 & \dots & C_i^0 & \dots & C_n^0 \end{vmatrix} \times \begin{vmatrix} P_{11} & P_{12} & \dots & P_{1j} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2j} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ P_{i1} & P_{i2} & & P_{ij} & \dots & P_{in} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nj} & \dots & P_{nn} \end{vmatrix}$$

.................Equation 2.24

Continuing with the Markov chain, the calculation of C (2) can be configured as follows;

$$C\,(2)= C\,(1)\times P$$

.................Equation 2.25

where C (1) is calculated by Equation 2. 24 and P is given in Equation 2.22.

This can be adapted to find the condition of the system after any number of time intervals; if t time intervals are considered, then C (t) can be represented through a common equation as follows (Equation 2.26):

$$C(t) = C(t-1) \times P$$

.................Equation 2.26

Equation 2.26 can be further simplified to Equation 2.27:

$$C(t) = C(t-1) \times P = C(t-2) \times P \times P = \ldots\ldots\ldots\ldots\ldots\ldots = C(0) \times P^{t}$$

.................Equation 2.27

Hence, the condition of the system at any time in the future corresponding with time intervals can be predicted using Equation 2.27. This is the fundamental theory applied in the Markov chain, but deriving the transition probability matrix is the challenge for all research problems. Depending on the situation, various approaches have been applied for this purpose, of which some use inspection data sets to derive the transition matrix (Mohseni et al., 2012a, Ranjith et al., 2013). In contrast, McDuling (2006) exploited a Neuro-fuzzy system (an artificial intelligence application discussed in Section 2.8.4) to derive the transition probability matrix.

2.12 Cost evaluation techniques

The valuation of income from properties depends on supply and demand in the market, and the cost and availability of capital for real estate investments. The valuation methods for income properties include the sales comparison approach, income approach and the cost approach. The sales comparison approach uses data from recent sales of properties highly comparable to the property being appraised. The income approach estimates the value of a property, based on its ability to produce cash flow. The cost approach determines the value of a property based on its construction cost, physical deterioration and obsolescence (Brueggeman and Fisher, 2010).

As community buildings owned by local councils are not intended for market sales or income generation, the sales comparison approach and the income approach are not suitable for estimating their values. The cost approach is difficult to apply, particularly if the property is not new and for a special use such as public utilization (Brueggeman and Fisher, 2010). Therefore, for community building valuation, an effort needs to be made to modify and supplement the cost approach, particularly in estimating the value of physical deterioration and obsolescence.

Past efforts in valuing building physical deterioration have mainly come from two perspectives. The first is monetary-derived, and focuses on the financial evaluation of a building taking account of the age and deferred maintenance. The other is engineering-derived and considers the physical deterioration and performance condition of the building. Typical techniques developed under the monetary-derived and engineering-derived building valuation approaches are reviewed seperately in the following sub-sections.

2.12.1 Monetary-derived building valuation metrics

Physical deterioration is the reduction in utility resulting from an impairment of physical condition, which can be curable or incurable (Brueggeman and Fisher, 2010). Curable deterioration refers to those defects which are repairable with maintenance, and the associated cost must not exceed the benefit to be realized by the cured deterioration (DTF, 2001). Curable deterioration is often expressed in terms of deferred maintenance. Incurable deterioration corresponds to non-repairable or incurable depreciation due to wear and tear, and the cost of curing the deterioration exceeds the corresponding gains recognized in the market value of the property (DTF, 2001). Typical examples of curable deterioration items include interior finish, floor covering etc., while incurable deterioration items include non-repairable or incurable foundation settling and structure defects.

For non-repairable physical deterioration, the lapse of time or age is often used as a factor to gauge incurable depreciation. Typical methods include the age-life, the sum of the years' digits and the reverse sum of the years' digits (Gyamfi-Yeboah and Ayitey, 2006). The age-life method estimates the accrued depreciation rate of a building,, the value of which will depreciate by the same amount every year, as shown in Table 2.31. Useful economic life is often used to count the valid life of a building. By definition, the useful economic life is the period of time over which the building is expected to be available for use and be able to provide the required level of services (Institute of Public Works Engineering Australia - New South Wales, 2009). The useful economic life of a building depends on the quality of construction material and workmanship as well as the location and environment of the building, and it can be a figure around 60 years (Dias, 2003).

The sum of the years' digits depreciation is a method of calculating the depreciation of an asset over the years. It assumes that a building will depreciate at a higher rate during the initial years of the building's life than at later years. In contrast, the reverse sum of the years' digits method claims that depreciation is slower initially and more pronounced later. The accrued appreciation rates can be calculated with the formulas shown in Table 2.31. Both the sum of the years' digits and the reverse sum of the years' digits methods assume the rate of deprecation per year has a linear relationship with age. This has been supported by empirical studies conducted by Follain and Malpezzi (1980) and Jones et al. (1981). .

Monetary maintenance backlog and facility condition index have been devised, based on the assessment of unfunded (deferred) work, for gauging curable physical deterioration, (Uzarski and Grussing, 2008). Depending on the building occupancy and the operation of facilities inside, a certain level of degradation occurs to building elements, which results in deficiencies and poor performance of the building and service systems. Through building inspections, deficiencies can be identified and estimated costs to correct them can be worked out. Due to the limited budget and the lack of resource availability for annual maintenance and repair, only the highest priority work will be funded and the deficiencies pertaining to the lower priority work will not be corrected through repair or replacement. As a result, a deferred maintenance backlog will develop over time. The total estimate of all deferred work over time determines the monetary maintenance backlog. By definition, the monetary backlog refers to the maintenance needs, expressed in monetary terms (costs) to bring up the related parts of the assets to a predefined standard (APPA, 2009).

The facility condition index (FCI) is a comparative indicator used to indicate the relative physical condition of a facility, group of buildings, or entire portfolio, independent of building type, construction type, location or cost. FCI is the ratio of the total deficiency backlog cost to the building's current replacement value (CRV), and is derived by assuming the building is new and then working out the value according to current rates (APPA, 2009). It provides a corresponding rule of thumb for the annual reinvestment rate (funding percentage) to prevent further accumulation of deferred maintenance deficiencies. FCI normalizes the simple monetary backlog by overall building economic value, so it is a more reliable indicator of the building's financial health. The FCI is represented on a scale of zero to one, or 0% to 100%, where higher FCI values represent poorer facility conditions. Although building owners/managers maintain independent standards, a "fair to good facility" is generally expressed as having an FCI of less than 10-15% (APPA, 2009).

Table 2.31 below presents the basic formula pertaining to each monetary-derived building valuation technique. Age-life, the sum of the years' digits and the reverse sum of the years' digits all use the accrued depreciation rate to gauge building deterioration. In comparison, the monetary maintenance backlog and facility condition index measure the value of the deferred maintenance.

Table 2.31: Monetary-derived building valuation metrics

Monetary-derived Building Valuation	Formula	Note
Age-life	Accrued depreciation rate= $\frac{N}{eL}$	*N*: age of the building
The sum of the years' digits	Accrued depreciation rate= $1-\frac{(L-N)(L-N+1)}{L(L+1)}$	*eL*: useful economic life of a building
The reverse sum of the years' digits	Accrued depreciation rate= $\frac{N\ (N+1)}{L(L+1)}$	*L* – life of a building
Monetary maintenance backlog	$MMB_t = \sum_i C_i$	MMB_t: monetary maintenance backlog at year *t*
Facility condition index	$FCI = \frac{MMB_t}{CRV}$	C_i: treatment cost for building element *i*
		i: elements with deferred maintenance
		FCI: facility condition index
		CRV: current replacement value

Source: (Zhang et al., 2010)

2.12.2 Engineering-derived building valuation metrics

The building condition index (BCI) approach is widely used in asset management to present physical condition information on building components and an overall health picture of a building. It emphasizes a structured inspection of predefined building components and investigates the distresses that exist in or might occur to those components. A distress “is a visual (or other observable) clue of a current or impending problem affecting the function of a building component” (Uzarski and Grussing, 2008). In this approach,curable physical deteriorations of building components are measured and recorded. The inspection process is well structured and the inspector has to prepare a predefined list of distresses in building components prior to carrying out the inspection. Experts such as engineers, architects and technicians are engaged in defining the distress types and severity levels, as well as the association of these distress types, severity levels, and densities with condition rating, and deduct values for components. Compared with deficiency-based methods such as monetary maintenance backlog, the BCI method is more comprehensive, consistent and systematic. As mentioned above, the distress information is collected at the building component level and can be combined to measure the overall building condition.

Based on the BCI, engineering-derived building valuation quantifies costs associated with the correction of distresses in building components as per the required actions described in Table 2.32 and then aggregates them to measure the physical deterioration value. Table 2.32 shows a typical metric defining building conditions at the component level, adapted from Abbott et al. (2007). A condition rating scale from 5 to 1, representing very good condition to very bad condition, is used to measure the condition status of components, reflecting their current ability to perform properly as they degrade from use, exposure, and/or other mechanisms. The corresponding action required for each type of condition is also presented.

Table 2.32: Building condition assessment metric

Condition Rating	Condition	Action Required	Description
5	Very Good	Planned Preventative Maintenance	The component or building is either new or has recently been maintained, does not exhibit any signs of deterioration.
4	Good	Condition Based Maintenance	The component or building exhibits superficial wear and tear, minor defects, minor signs of deterioration to surface finishes and requires maintenance/ servicing. It can be reinstated with routine scheduled or unscheduled maintenance/ servicing.
3	Fair	Repairs	Significant sections or component require repair, usually by a specialist. The component or building has been subjected to abnormal use or abuse, and its poor state of repair is beginning to affect surrounding elements. Backlog maintenance work exists.
2	Bad	Rehabilitation	Substantial sections or components have deteriorated badly, suffered structural damage or require renovations. There is a serious risk of imminent failure. The state of repair has a substantial impact on surrounding elements or creates a potential health or safety risk.
1	Very Bad	Replacement	The component or building has failed, is not operational or deteriorated to the extent that does not justify repairs, but should rather be replaced. The condition of the element actively contributes to degradation of surrounding elements or creates a safety, health or life risk.

Source: (Zhang et al., 2010, Abbott et al., 2007)

The condition profile of a component is the percentage of the component in various condition categories. In other words, different portions of a component may be in different conditions at the same point of time (Abbott et al., 2007). On the other hand, not all components in a building require to be maintained at the same standard. Multiple condition standards may exist and components will be assigned different levels of condition standards, depending on the impact on organizational goals and associated risks (Grussing et al., 2006). Condition assessments are conducted at the building component level and the costs associated with different maintenance actions, such as planned preventive maintenance, condition-based maintenance, repairs, rehabilitation and replacement are calculated. Table 2.33 presents a matrix for calculating the value of physical deterioration for one component, which reflects the budget requirement to rectify the defects to the desired level. Likewise, a budget for every component will be calculated. By accumulating the budget requirements for all the components, the total requirement for rectifying the curable physical deterioration of the building can be calculated.

Table 2.33: Matrix for calculating value of physical deterioration of a building component

Condition (rating)	Very Good (5)	Good (4)	Fair (3)	Bad (2)	Very Bad (1)
Assessment percentage	Pct_5	Pct_4	Pct_3	Pct_2	Pct_1
Action required	Planned Preventative Maintenance	Condition-based Maintenance	Major Repairs	Rehabilitation	Replacement
Cost associated with action required if 100% of the building component is in a particular condition	C_5	C_4	C_3	C_2	C_1
Average condition rating index	Average condition rating = Pct_5*5+Pct_4*4+Pct_3*3+Pct_2*2+Pct_1*1				
Value of physical deterioration of a building component	Value of physical deterioration = Pct_5* C_5+ Pct_4* C_4+ Pct_3* C_3+ Pct_2* C_2+ Pct_1* C_1 Where $Pct_5 + Pct_4 + Pct_3 + Pct_2 + Pct_1 = 100\%$				

Source: (Zhang et al., 2010)

2.12.3 Measurement of obsolescence

Obsolescence is a measure of the difference between qualities exhibited by the subject building and the desired market qualities expected in a similar building type (DTF, 2001). As a major cause of depreciation, obsolescence should be taken into consideration when valuing a building. It is defined as a value of decline due to functional, external or legal reasons, or due to its location, aesthetics or physical construction aspects (Caccavelli and Gugerli, 2002). Functional obsolescence refers to depreciation resulting from internal building features that make the building less livable or marketable than it was when first constructed. Typical examples include excessive hallway space, and out-of-date building services. External obsolescence is caused by factors external to the building, such as changing land uses in a neighbourhood, pollution, changing legal restrictions on land or building use (Caccavelli and Gugerli, 2002, Brueggeman and Fisher, 2010).

Human perceptions and decisions largely influence the evaluation of obsolescence, which potentially increase the unreliability of the assessment or prevent people from taking it into consideration. Most recent research tends to narrow the scope of obsolescence and emphasize functional-based obsolescence (Caccavelli and Gugerli, 2002, Gyamfi-Yeboah and Ayitey, 2006). One way of measuring functional obsolescence is to estimate the extra cost associated with using the building in question as compared to using a similar but more efficient building, and the accuracy of the estimation relies on the appraiser's overall knowledge of the market (Gyamfi-Yeboah and Ayitey, 2006, Brueggeman and Fisher, 2010). For example, the appraiser estimates that due to functional obsolescence, the operation cost of a subject building will be $20,000 per year higher compared with a completely new building, and then this amount of money is deemed to be the annual value of functional obsolescence. A similar approach can be used to measure external obsolescence. For example, if the change of the external environment results in lower rent and/or higher expense for a building, then this loss is regarded as the value of external obsolescence.

2.13 Concluding Remarks

The foregoing literature review has examined the most important features related to the outcomes of the present research. An extensive review has been undertaken on the sustainability of buildings, and derived four aspects: environmental, economic, social and functional to measure corporate sustainability. This was followed by a review of building assessments the aim of which was to capture the factors influencing these aspects. Two different building assessments; Environmental assessments and life cycle assessments, were critically reviewed based on three criteria. The first criteria identified the level of assessment whether it focuses on “building product” or “building” or “community”. The review process captured different criteria and they compared against each model. The review suggested that there is no assessment model with a broader focus of sustainability capturing all four aspects above mentioned. The third major criteria involved in the critical review were the weighting system applied in their assessments. It showcased the weighting systems of current models, except BEES, are absence of mathematical or scientific based system. Capturing of factors continued to review building management models but most importantly, the section was to understand the architecture of the current building management models. Five different models for two decision making aspects were reviewed in the section. The factor method and EUROLIFEFORM were to predict building deterioration whereas EPIQR, MEDIC and TOBUS were to plan building retrofits. However, it was obvious that these models are not capable of planning maintenance actions of buildings.

The review of generic infrastructure asset management systems was to map the research outcomes best fitted with the anticipated goals set by the asset management system. It identified three general asset management processes included in the strategic asset management system regardless of the asset type. They are strategic analysis, strategic choice, and strategic implementation. Decision-making is a vital part of the asset management system which identified the significance of using multi-attribute decision-making methods to the current research problem. Among them, the research identified the appropriateness of AHP method using in the research problem hence; paramount importance was given to AHP under the literature review chapter. The section was first delivered explaining the concept of AHP and followed by its practical applications. Several previous studies were supported to present AHP’s practical applications. Similarly, Artificial Intelligence (AI) applications were selected for suitable sources of using in the evaluation process. Therefore, different AI applications were explored and Neuro-fuzzy systems were best chosen for the current application. As in the AHP section, same method was used to deliver the idea of Neuro-fuzzy systems. The theory was first extensively explained and clarified the theory by its practical applications.

The review of condition monitoring of buildings and building hierarchy systems identified their importance to the development of the decision-making model. Hence, the research set the condition rating method and the building hierarchy system prior to develop the model. One to five condition rating method was the default condition rating method for the research whereas NAMS building hierarchy was for the building hierarchy system. Deterioration prediction and cost evaluation techniques were correlated with integrated decisions hence, some of their findings through the review were utilised for making integrated decisions. Deterioration prediction was mainly focused on Markov process based predictions due to its potential application in the ongoing parallel research. Cost evaluation techniques were described based on two valuation principles. They are monetary-derived building metrics and engineering-derived building metrics. The section also discussed the measurement of obsolescence in buildings.

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research design, research process and ends with concluding remarks.

3.2 Research design

The research design was based on the research questions and research objectives. The aim of the research design was to find strategies in the form of action plans to answer the research questions and achieve the anticipated outcomes. According to Bediawan (2003), it is important in configuring the research project to consider: what kind of evidence is gathered; from where such evidence is gathered; and how such evidence is interpreted. According to Sekaran and Bougie (2010), six issues to be answered: purpose of the study; type of investigation; extent of research interference; study setting; unit of analysis; and time horizon. These issues are discussed in the following sub-sections.

3.2.1 Purpose of the study

According to the rationale of the present research, it can be interpreted as a combination of "pure" and "applied research". By definition, "pure" research attempts to discover new theories, laws of nature, etc. whilst "applied" research tends to carry out the research looking at the end uses and practical applications (Fellows and Liu, 2008). There are several ways of classifying a research study based on different features of the study. One way that the research can be identified is based on its process. Hence, it can be categorised as "quantitative" or "qualitative" (Fellows and Liu, 2008). Another way is to classify research studies based on their purpose. Accordingly, Fellows and Liu (2008) identify five different classifications: instrumental, descriptive, exploratory, explanatory, and interpretive. However the research is classified, the nature of the study depends on the level of knowledge reached on the research topic (Sekaran and Bougie, 2010).

Exploratory studies are undertaken to find out "what is happening; to seek new insights; to ask questions and to assess phenomena in a new light" (Robson, 2002). Exploratory research is conducted when there is a lack of information on the existing situation, or as a mean to solve similar research problems that occurred in the past where very few studies have been carried out previously (Sekaran and Bougie, 2010). In this case, there are principal ways of capturing information in an exploratory research, including search of literature, talking to experts on the subject and capturing their ideas through questionnaires or focus group interviews. In contrast, interpretive studies are undertaken to fit findings/experience to a theoretical framework or model; such research is necessary when empirical testing cannot be done (Fellows and Liu, 2008).

The purpose of the present research is to develop an integrated decision-making framework for the sustainable management of community buildings in Australia. As the literature review has shown (see Chapter 2), very few studies have been undertaken on the topic and existing systems need improvement. The present study includes several tasks including exploring the current system; searching of the literature and interviewing experts in the area to understand sustainability and key factors in the management of community buildings. On the basis of the characteristics of the present research and the way it was implemented, it can be classified as a wholly exploratory research study. However, it involves some mathematical techniques and determines the relationship between variables and measures their behaviour through a model. In this case, the study becomes a partly interpretive research study. Hence, the research uses a combined exploratory and interpretive methodology.

3.2.2 Type of investigation

Depending on the research questions, the researcher can decide the type of investigation, whether causal or non-causal (correlational) (Sekaran and Bougie, 2010). At the initial stage, if the researcher discovers a pattern of cause-effect relationship of the variables of the problem and it is necessary for the research outcomes, then undertaking a causal type of investigation is unavoidable (Bediawan, 2003). However, if the researcher is merely interested in delineating the important factors, then a non-causal type of investigation is the most appropriate (Bediawan, 2003, Sekaran and Bougie, 2010).

The present research identifies multiple factors affecting different sustainability aspects. Together with factors and related aspects, corporate sustainability is identified and measured. Phase 1 delineates the important factors and aspects. Therefore, Phase 1 adopts a correlational type of investigation. However, the research involves another phase (Phase 2), which measures the corporate sustainability impact of a given building component, which is the ultimate effect derived from factors and aspects. The problem can be explained through a cause-effect relationship, making Phase 2 a causal type of investigation.

3.2.3 Extent of researcher interference

According to Sekaran and Bougie (2010), the extent of researcher interference varies depending on the study being carried out, whether causal or correlational. In a correlational study, in contrast with a causal study, the researcher has a comparatively minimal interference with the usual flow of work in the natural environment of the organization. This is true, even though some disruption occurs to the usual flow of work at the workplace in a correlational study, as the researcher interviews employees and administers questionnaires. They also identify the reason for generating higher interference in a causal study as being due to the deliberate manipulation of certain variables in order to study their effect on the dependent variable of interest.

The present research distributed the first questionnaire (see Appendix B) to capture the opinions of industrial practitioners who work in the community building sector, regarding the factors affecting sustainability. This was a correlational approach and the questionnaire was designed to enable respondents to express their opinion. Therefore, the interference in the working environment of the industry practitioners by the researcher was minimal during this stage of data collection. The second questionnaire (see

Appendix C) was designed to capture the weightings of criteria according to the dependent features of interest, which was a causal study. The rest of the process of cause and effect analysis was purely analytical, interference occurred only through the questionnaire. The questionnaire only sought pair-wise comparison data of criteria, but did not manipulate the variables (criteria). Therefore, the interference to the working environment of the industry practitioners from the researcher was minimal even in that phase of data collection.

3.2.4 Study setting

There are two types of study settings: contrived and non-contrived. Correlational studies are invariably conducted in non-contrived setting, i.e. in the natural environment where events normally occur. In contrast, rigorous causal studies are done in artificial, contrived settings (Sekaran and Bougie, 2010).

The present research comprises a correlational study and a non-rigorous causal study where the events occurred naturally in the field of community buildings, and there was minimal researcher inference. As the events occurred naturally and with minimal researcher interference, the appropriate study setting of this research is non-contrived.

3.2.5 Unit of analysis

Sekaran and Bougie (2010) defined the unit of analysis as the level of aggregation of the data during subsequent analysis, and it has to be determined at the stage when the research questions are formulated. Hence, the unit of analysis may be individuals, dyads (two persons), groups, divisions or industries.

The data used in this research were collected from practitioners working in the area of management of community buildings through questionnaires. The data collections were planned to answer some research questions concerned with the management of community buildings. Hence, the unit of analysis of this research was the community building division in local government sector of Australia.

3.2.6 Time horizon

Studies can be "cross-sectional" or "longitudinal", depending on the time horizon of the study. Studies in which data are gathered only once in order to answer research questions and represent a "snapshot" of one point in time are called cross-sectional studies. In contrast, longitudinal studies capture data required for answering the research questions more than once across a period of time (Sekaran and Bougie, 2010).

The research data for the present study were collected once over a period of months from practitioners in the management of community buildings. Therefore, this research is a cross-sectional study.

3.3 Research process

The research process is the action plan generated by the research design. This involves the planning of the actual study dealing with aspects such as: choosing the location for the study; how to select the sample and collect the data; and how to analyse the data (Sekaran and Bougie, 2010). In general, it is comprised of and flows through the following steps:

- Data collection
- Data analysis
- Obtaining research outcomes
- Discussion
- Summary

A detailed outline of the activities of the present research process is as follows:

- Capturing the current practice
- Identifying corporate sustainability of community buildings through its dependent aspects
- Development of a conceptual framework
- Data collection methods- obtaining influencing factors for each sustainability aspect
- Data analysis

- Development of a comprehensive decision-making hierarchical structure
- Development of a decision-making model
- Integrated decisions incorporated with maintenance programs, cost and life cycle

Each of these stages is discussed in the following sub-sections.

3.3.1 Capturing the current practice

As stated in Section 1.6, a preliminary data collection was conducted to explore the current practices of six councils associated with the project. Table 1.1 illustrates the summary of the results based on responses to a questionnaire given at council visits. The results covered seven strategic areas of the management of community buildings. In this section, each council's responses are discussed.

Council A

Council A practised a basic building maintenance strategy with a reactive decision-making model. This council did not assess building condition on a regular basis and used the building valuation data for decision-making. However, this council had conducted some ad-hoc maintenance and condition audits of facilities for disabled people. In these audits, no element hierarchy was used. A list of 24 elements was used without identifying the criticality of these elements. The condition rating used in these audits was on a scale of 1 to 5. The data collection method used in the condition audits and building valuation was visual inspection.

The council did not use any deterioration prediction method. Overall budgeting combined with spread sheet calculations based on Moloney's model (IPWEA, 2009) was used in cost forecasting. The council applied risk mitigation in trade packages when work orders were contracted out. Decision-making primarily took stakeholder needs into account; however there was the possibility of making politically-influenced decisions. At the time of data collection, Council A had completed a two-year environmental sustainability plan and was also in the process of undertaking another three year environmental sustainability plan on green buildings.

Council B

Council B used some features of the generic infrastructure management system (see Section 2.5). Following an element hierarchy introduced by Urban Maintenance Services (UMS), the council collected building condition data annually. It later mapped the UMS element hierarchy with Moloney's element list (which consists of building structure life, roof structure, mechanical services and building fit out) in the cost forecast process, together with Cashflow5. In addition to cost forecasting, the council utilised Cashflow5 for decision-making. Cashflow5 incorporates several accounts in capital budget decisions such as stakeholder, scope, design, permits, cost estimation, timeline, community, strategy, commitment and economic, environmental and social factors. This council also adopted visual inspection as the preferred data collection method, while Moloney's condition rating scale (0-10)(IPWEA, 2009) was the preferred rating method. None of the deterioration prediction models was applied in their practice.

Council C

Council C conducted three types of building assessments. First, was the regular annual condition audit of building components. Second was tracking building components for whether a replacement was needed or reported. The third assessment was for the purpose of capital budget and it was conducted on ad-hoc basis of decision-making. Accordingly, the council was in the process of developing an in-house 10-year renewal program. The program used condition (fit for use), serviceability (fit for purpose) and sustainability in deciding renewals, together with considerations of capital works and criticality. The council adopted its own element hierarchy and the condition rating of 1-5 for condition monitoring. Using hierarchy and the condition rating method, the council collected data through visual inspection. No deterioration prediction model was run by the council.

Council D

Council D conducted condition audits every two years. The council decided its own list of elements to be used in their condition audits. This was the only council that recorded material and age of individual elements in condition audits. The council also provided condition auditors with a guideline/manual to follow up before conducting any condition audit. The guidelines considered the deterioration curve enclosed in the condition assessment. Therefore this council had made some effort on deterioration prediction. The condition was monitored using a 1-5 condition rating scale and the way of capturing condition was visual inspection in every condition audit. The council was seeking to adapt rules from the Pavement Management System (PMS) (SMEC, 2013) for buildings for cost forecasting and decision-making. The decision-making model was in progress at the time of data collection.

Council E

Council E conducted both building condition assessments and building valuations, the former every year and the latter every two years. The council maintained its own detailed element hierarchy and 1-5 condition rating method for their condition assessments. In condition audits, the council provided a detailed condition assessment manual/guideline to the auditors in advance. Similar to all previous councils, the data collection method of this council was visual inspection. The cost forecast and decision-making method of Council E was currently in progress, a comparatively big step towards an advanced approach beyond the approaches of previous councils. The physical condition rating of the building was integrated with other influencing factors such as environment, amenity – equity, service, children's services, grounds & gardens, sewer, stormwater, housekeeping and safety. Maintenance planning and decision-making was done based on building categorization, building priority and building weightings (e.g. buildings of state significance, regional significance, municipal significance and neighbourhood significance). For budget allocations, the council seeks involvement of appropriate committees and consults them.

Council F

Council F conducted building condition assessments based on its own detailed element hierarchy, which follows 1-10 condition rating scale. The data collection method of the council was also visual inspection. The development of the cost forecasting and decision-making method of Council F was in progress and exhibited some similar features to that of Council E. Similarly, the physical condition rating of the building was integrated with other influencing factors such as the environment, essential services, children's services and safety. In their approach, maintenance planning and decision-making was done only based on building weightings. At that time, the council was planning to identify the significant elements among the element hierarchy by introducing an associated criticality factor and using it in the decision-making process. However, no steps had been taken on deterioration prediction.

Gap identification (in practice)

Based on the summary of how six partner councils manage their community buildings in seven strategic areas, one main gap is visible:

- It is clear that asset managers in local councils are in urgent need of an integrated decision-making structure to support the design, planning and management of community buildings

3.3.2 Identifying the corporate sustainability of community buildings through its dependent aspects

Aspects involved in the sustainable management of community buildings are reported in this sub-section. On searching for dependent aspects, the study was first based on general “triple bottom line” sustainability aspects, as stated in Section 2.2.1. Being focused on buildings and their sustainable management, the study covers the additional “Functional aspect”, as stated in Section 2.2.2. The inclusion of these four aspects in the sustainable management of community buildings was validated by the partner councils. Hence, the study continued with four dependent aspects relevant to the sustainable management of community buildings namely: environmental, economic, social and functional, as shown in the following Figure 3.1.

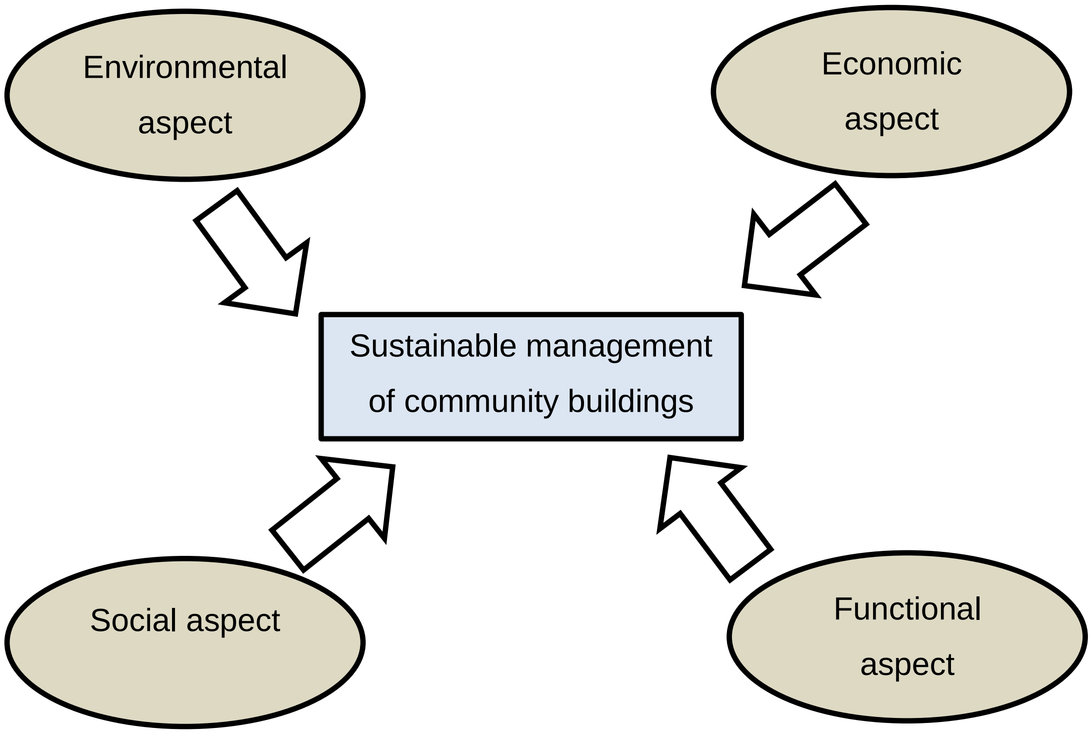


Figure 3.1: Aspects of the sustainable management of community buildings

3.3.3 Development of a conceptual framework

The design of the study focused on essential features of a generic asset management system for the sustainable management of community buildings. All the features were placed in a conceptual framework in order to facilitate the study of the sustainable management of community buildings. Figure 3.2 illustrates the flow of the conceptual framework, highlighting six features.

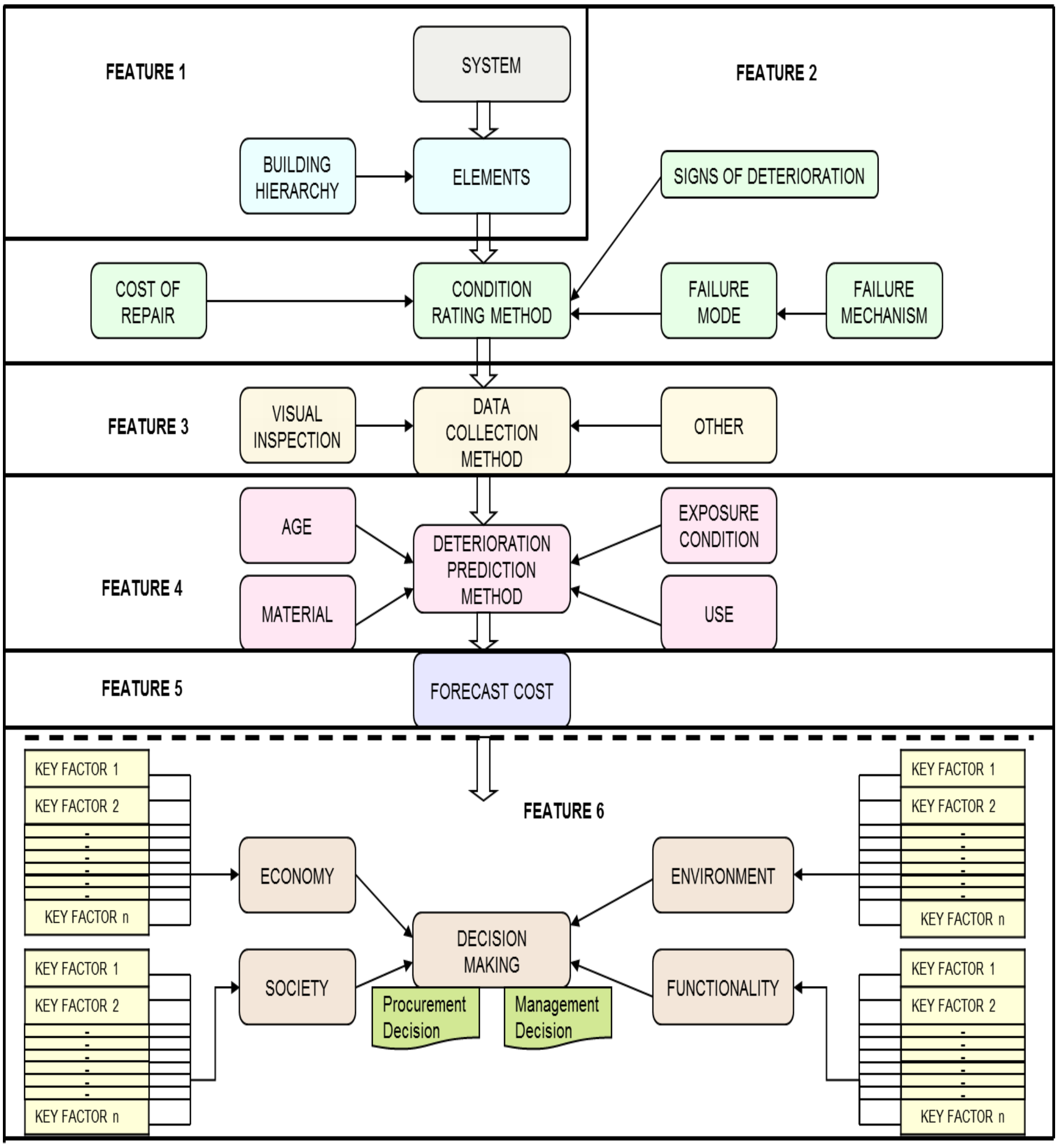


Figure 3.2: Conceptual building management framework of the research

Feature 1 links the council's building system with the established element (component) hierarchy of the building. A council building system can be categorised according to the type of building, such as aged care centre, childcare centre, civic centre, sports centre and so on. However, the council may adopt a standard element hierarchy for all buildings which have elements in common for each building. A building element represents the detailed level of any management approach. Hence, it is essential to follow it at every level, even though managerial decisions are taken on immediate levels of the hierarchy. For example, the National Asset Management Strategy Australia

(NAMS.AU) hierarchy (IPWEA, 2009) uses three levels to represent a building element or component. It follows from “component group” to “component type” to “component” hierarchically. Depending on the management strategies of the council, the level of the hierarchy (whether component group or component type or component) will be decided for managerial decisions.

The building element hierarchy suggested by NAMS.AU covers around 90% of commonly replaceable building components, regardless of the building type, making it more comprehensive and easy to use. For this reason, the web-based software (CAMS) (see Chapter 9), developed as an outcome of the research, encapsulates the NAMS hierarchy as the default element hierarchy. In addition, the software provides flexibility to councils to use their own hierarchies according to their preference.

Feature 2 represents the condition rating method of the council. For consistent condition data, the condition rating method should focus on aspects which highly influence the state of the building such as: signs of deterioration, cost of repair and the failure mode considering potential failure mechanisms. Accordingly, rating scales incorporating linguistic descriptions can be involved in the condition rating method. The CAMS adopts a 1 to 5 rating-scale because this rating system is the most widely used in practice not only for buildings but also for all other infrastructure asset classes. In addition, most manuals or specifications of condition ratings are based on 1 to 5 scales, making such scales simpler for inspectors.

The collection of condition data for assessment and analysis purposes is the focus of **Feature 3**. The basic mode of all local councils for data collection is visual inspection, whereas some other destructive and non-destructive tests are used in special circumstances. Visual inspection is subjective, but the subjectivity can be minimised by recruiting the same personnel for regular inspections. Making inspections more frequent and regular can further improve the consistency of data.

Feature 4 describes deterioration prediction, which is another important aspect of the management of community buildings. This aspect was explored in detail in the research parallel with the current research (Mohseni, 2012).

The method used in that research was a Markovian model, which was used to manipulate condition data to develop the transition probability matrix and to develop a deterioration prediction model.

Feature 5 focuses on cost forecasting to maintain the performance of a given component under its ongoing deterioration. Section 3.3.8 and Chapter 8 deal with this feature.

Feature 6 addresses decision-making in relation to the sustainable management of community buildings. This is the main focus of the present research.

3.3.4 Data collection methods- obtaining influencing factors for each sustainability aspect

Data collection through a combined process of literature review and focus-group meetings with partner councils

A systematic process was followed to identify key factors which influence the sustainable management of community buildings through four aspects: environmental, economic, social and functional. The process first captured data from the literature review, as stated in Sections 2.3 and 2.4 above. They were then shown to the partner councils and tailored to the sustainable management of community buildings, according to their opinions, comments and feedback. This process generated 67 preliminary factors influencing the sustainable management of community buildings through four sustainability aspects. The individual contribution to the list from the environmental aspect was 23 factors, whereas the economic aspect contributed 13 factors. The rest of the list comprised factors relating to the social and functional aspects, with 17 and 14 respectively. The tabular representation of the individual lists for each aspect is given in Tables 3.1, 3.2, 3.3 and 3.4.

Table 3.1: Factors influencing the environmental sustainability of community buildings

Factors influencing the environmental sustainability		
Factor No	Code	Factor
1	En1	Reduction of GHG (Green House Gas) emission
2	En2	Amount of noise pollution
3	En3	Amount of air pollution
4	En4	The amount of green energy consumption
5	En5	The amount of energy consumption
6	En6	The amount of used materials with low embodied energy
7	En7	Impact on energy use
8	En8	Lighting efficiency
9	En9	Sourcing materials locally
10	En10	Building reuse
11	En11	Cyclist facilities
12	En12	Use of rain water
13	En13	Recycling of grey water
14	En14	Impact on quality storm water run-off
15	En15	Impact on potable water use
16	En16	Thermal comfort
17	En17	Indoor air quality
18	En18	Impact on air quality
19	En19	Usage of hazardous goods and materials (e.g. asbestos)
20	En20	Refurbishment of noise & pollution
21	En21	Usage of recycled materials
22	En22	Construction waste management
23	En23	Operation waste management

Table 3.2: Factors influencing the economic sustainability of community buildings

Factors influencing the economic sustainability		
Factor No	Code	Factor
1	Ec1	Additional capital investment cost
2	Ec2	Maintenance and renewal cost
3	Ec3	Replacement cost
4	Ec4	Operation cost
5	Ec5	Residual value including land value
6	Ec6	Routine maintenance cost
7	Ec7	Local employment opportunity
8	Ec8	Use of local materials and local suppliers
9	Ec9	Revenue generation for the council
10	Ec10	Community land value (Depending on the current market value)
11	Ec11	small business advancement in the local government area
12	Ec12	Tourism significance
13	Ec13	Minimizing life cycle costs

Table 3.3: Factors influencing the social sustainability of community buildings

Factors influencing the social sustainability		
Factor No	Code	Key factor
1	Sc1	Equity of employees
2	Sc2	Equity of users
3	Sc3	Provision of recreational and essential facilities
4	Sc4	Accessibility
5	Sc5	Community's health/well-being (The hygienic condition)
6	Sc6	Feeling of security
7	Sc7	Impact on healthy life style
8	Sc8	Usage of hazardous goods and materials
9	Sc9	Heritage value of the building
10	Sc10	Image of the council
11	Sc11	Aesthetics
12	Sc12	Local community involved
13	Sc13	Local community expectation
14	Sc14	Local community support
15	Sc15	Level of community demand
16	Sc16	Number of community members that will benefit
17	Sc17	Proximity via public transport, cycling, walking

Table 3.4: Factors influencing the functional sustainability of community buildings

Factors influencing the functional sustainability		
Factor No	Code	Key factor
1	Fn1	Number of users affected due to failure
2	Fn2	Severity of failure
3	Fn3	Length of interruption to service
4	Fn4	Availability of alternative resources
5	Fn5	Adaptability of users to a proposed change
6	Fn6	Likelihood of failure
7	Fn7	Facilities and services management
8	Fn8	Minimum acceptable level of service
9	Fn9	Accountability to users
10	Fn10	The ability to meet short term demands
11	Fn11	The ability to meet long term demands
12	Fn12	Compliance to the Building Code
13	Fn13	Compliance to the OHS standards
14	Fn14	Compliance to disability

A long list of factors (more than 10) is a characteristic of each table above. In the assessment process, these criteria were to apply to the building component, the bottom level of the component hierarchy of the building (e.g. NAMS hierarchy). This initiated a long and time-consuming process which gives an impractical solution to the overall sustainable assessment of the given building component. Therefore, refinement of these factors was essential for a practical solution to the anticipated outcome of the research. A thorough investigation of the lists of factors showed that some factors exhibit common features, so that they could be compiled in common groups. On the other hand, the literature suggests that extraction of variables to common factors could be done using factor analysis, which is a statistical application. Factor analysis is done based on the correlation of each variable with another (Child, 2006, Gorsuch, 1983). Hence, responses to a questionnaire, focused on a selected attribute of the variables, can be manipulated to acquire the correlations (Field, 2009). The researcher conducted a questionnaire for this purpose (see Appendix B), and completed the factor analysis enabling the refinement of the factors (see Chapter 4).

Data collection through a questionnaire survey

Questionnaire development

The most important thing before the design of a questionnaire is that the researcher should be aware of what exactly is required and how the measurements of the targeted variables are obtained from the questionnaire (Sekaran and Bougie, 2010). Sekaran and Bourgie (2010) further identify three principles to be followed for the design of an effective questionnaire. The first principle relates to the wording of the questionnaire, whereas the second principle relates to issues of how the variables will be categorised, scaled, and coded according to the responses. The third concerns the appearance of the questionnaire, which basically means the length. A pilot survey is an effective method to confirm whether the three-principles have been effectively met in the draft questionnaire.

Pilot study

The pilot testing of a questionnaire is essential to test whether the questions are intelligible, easy to answer and unambiguous. It also helps to improve the questionnaire in terms of ease of completion and determining the required time (Fellows and Liu, 2008). According to Dillman (2007), people who are knowledgeable colleagues and analysts can be involved in the activity of pre-testing a questionnaire by submitting the final questionnaire to them. Analysts in this case can be experts or the targeted respondents.

According to Robson (2002), there are two stages of piloting. The first stage is an informal way in which researchers can cajole their colleagues, friends and family into reading the questionnaire. The second stage is that researchers can engage respondents from the groups of interest. This can be done on an individual basis, asking them to give any thoughts that occur to them when the question is read out (Robson, 2002). The intention is to help the researcher understand the meaning of the question to respondents, and how they arrive at their response, and to help improve the wording. It is an approach widely used by cognitive psychologists, known as *protocol analysis* (Ericsson and Simon, 1985). An alternative is to use focus groups to help improve not only question wording but other aspects of the survey (e.g. the length, wording of covering letter) (Robson, 2002).

The current research adopted an approach no different to a common pilot survey. Once the initial draft was prepared, it was presented to and tested by five members of the research team, including my two supervisors, two research fellows and one of my colleagues (a PhD student). Having modified the questionnaire based on their responses, the second stage of pre-testing was designed. The asset managers in the partner councils who work in the management of community buildings were engaged in responding to the draft questionnaire. The reason for the selection of asset managers was that they were the practitioners in the area of the questionnaire, thus the experts. Based on their responses and remarks, the final questionnaire was designed (see Appendix B).

Industry-wide questionnaire 1

As mentioned above, the main purpose of conducting a questionnaire was to do a factor analysis of the responses and to refine the key factors for each sustainability aspect. Due to the fact that four sustainability aspects are considered here, in reality, four questionnaires exist in the one questionnaire disseminated to the industry. The questions were asked based on one attribute of factors under each aspect which was used to generate correlations of factors with one another. The attribute was the validity of factors being represented or used under a selected sustainability aspect. The validity was extracted from the responses to a Likert scale of 1-5, representing the absolute values of five linguistic terms. Each linguistic term was provided with a range of numbers so that the confidence of agreement varied. Table 3.5 shows how each linguistic term varies in the given range of numbers.

Table 3.5: Rating scale classification

Linguistic agreement	Number range
Strongly disagree	1 to 1.5
Disagree	1.5 to 2.5
Neither agree nor disagree	2.5 to 3.5
Agree	3.5 to 4.5
Strongly agree	4.5 to 5.0

Most of the questionnaire included closed questions, to which the respondents answered based on a number of predetermined alternatives using Likert scale agreements. On the other hand, some of the questions were open-ended, which gave respondents the freedom to choose the answer on their own. For example, the following question was included immediately after the responses to validation of the key factors of each aspect:

If there are indicators missing from the above list, please add them below.

The questionnaire consisted of two sections, A and B. Section A sought demographic data in five different questions. They were designed in order to preserve anonymity as required by the ethics approval received from the ethics committee of the university. The answers to these five questions were for information but not for the purpose of analysis. Section B contained questions related to the validation of the key factors of each aspect. The total questionnaire is in Appendix B, and examples of questions for two sections are shown in the next sub-section.

The respondents to the questionnaire covered professionals from local councils in Australia (such as building managers, building engineers, infrastructure asset managers, infrastructure engineers), who were directly involved in the management of community buildings. They were experts concerned with the area of questions in the questionnaire; therefore they were undoubtedly the most appropriate respondents. However, only one response was obtained from each local council, hence the response was assumed to be the collective decision of the council. The questionnaire was web-based, and created electronically using a survey website called "Survey Monkey". The format of the questions in Section B was designed as one question to one aspect. Answers for underlying factors of the aspect were delivered in the format of a matrix of choice, which focussed the respondents' concentration on the same aspect. The length of the time taken for complete responses was 20 minutes on average, based on the pilot survey results. The total questionnaire is presented in Appendix B.

Example questions of the questionnaire

Section A

1. Respondent's Current Position:

2. How long have you been working in the current position:

3. Number of buildings under management of the council:

4. Please insert the state in Australia where your organisation is located:

5. Total years of work experience in building management:

Section B

Please indicate your view using the following indicators to measure the environmental impact. (For example, if you consider ‘Reduction of GHG emission’ as a major indicator to be included for environmental impact, please tick your selection of ‘Strongly Agree’)

Key Indicator	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Reduction of GHG (Green House Gas) emission					
Amount of noise pollution					
Amount of air pollution					
The amount of green energy consumption					
The amount of energy consumption					
The amount of used materials with low embodied energy					
Impact on energy use					
Lighting efficiency					
Sourcing materials locally					
Building reuse					
Cyclist facilities					
Use of rain water					
Recycling of grey water					
Impact on quality storm water run-off					
Impact on portable water use					
Thermal comfort					
Indoor air quality					
Impact on air quality					
Usage of hazardous goods and materials (e.g. asbestos)					
Refurbishment of noise & pollution					
Usage of recycled materials					
Construction waste management					
Operation waste management					

Validity and reliability of the responses to the questionnaire

According to Sekaran and Bougie (2010), validity tests have three major forms: content validity, criterion-related validity and construct validity. Moreover, they emphasise that content validity requires an adequate and representative set of items pertinent to the measure with the concept. The present research formulated sets of factors influencing all four sustainability aspects and validated them using the responses of six partner councils. This was adequate for the content validity of the questionnaire. However, analysis of the responses revealed that the average index (mean) of every factor was equal to or greater than 3.5, which was clearly in the zones of "Agree" and "Strongly Agree". This further validated the contents of the questionnaire as being not only based on the results of six partner councils but also in the context of most local councils in Australia.

Criterion-related validity is only required when the measure differentiates between individuals responding to a criterion and hence has an impact on the result. Concurrent validity of individuals must be established in order to measure the discrimination between individuals who are known to be different and therefore their scores are different on the test (Sekaran and Bougie, 2010). The researcher consulted industrial professionals who work in the management of community buildings. Despite the respondent being called a building manager, building engineer and so on, the response was assumed to be a collective decision of each local council, coming from the team involved in the management of community buildings. Hence, there was no distinguishable difference in responses by respondents and no requirement to do criterion-related validity checks.

Construct validity is related to the theories on which the analysis of responses is based. The questionnaire focused on refinement of data through factor extraction, hence factorial validity was the assessment required for the construct validity of this questionnaire. This can be done by submitting the data for factor analysis (Sekaran and Bougie, 2010). Factor analysis can be used to ascertain a relatively small number of factors, which in turn can be used to represent relationships amongst sets of many interrelated variables (Aksorn and Hadikusumo, 2008). According to the present research, the results of factor analysis confirm the factors represent each sustainability aspect. Sample size is very important in the context of the reliability of the results of factor analysis, and ultimately impacts on factorial validity. In this regard, one recommendation by Hair (1992) is to obtain responses from at least four to five times the number of variables. The second recommendation is to obtain more than 100 responses if possible (Hair, 1992). In addition, statistical tests, such as Kaiser-Meyer-Olkin (KMO) and Bartlett’s test of sphericity, were used to discover whether they were in the specified value range to further ensure factorial validity (Kaiser, 1974, Hutcheson and Sofroniou, 1999, Field, 2009, Hair, 1992). The results of factor analysis related to the current study are presented in detail in Chapter 4.

The reliability of a measure indicates the stability and consistency with which the instrument is measuring and helps to assess the goodness of a measure (Sekaran and Bougie, 2010). In other words, instruments and procedures should produce the same results when applied to similar people in similar situations or the same people on a second occasion (Sommer and Sommer, 1992). The most popular and most accepted test of inter-item consistency reliability is the Cronbach's coefficient alpha (α) , which reflects the positive correlation of items in a set to one another (Hinton et al., 2004, Field, 2009, Sekaran and Bougie, 2010, Cronbach, 1951). The value of α varies from 0 to 1 and Nunnally (1975) recommended that there exists an acceptable consistency reliability in most research situations if α equals or is greater than 0.70. On the other hand, Hinton et al (2004) provided cut-off points for α and related interpretations of consistency reliability. According to these researchers, the range in which α is equal or greater than 0.90 indicates "Excellent reliability" whereas the range in which α is 0.70 to 0.90 indicates "High reliability". Similarly, the ranges of 0.50 to 0.70 and below, or equal to 0.50 represent "Moderate reliability" and "Low reliability" respectively. Hence, their guide to interpreting α value with consistency reliability also supports Nunnally's (1975) recommendations. The results of α value for the items pertinent to each sustainability aspect in the present study are presented in Chapter 4.

3.3.5 Data analysis

Once all the responses were obtained for the questionnaire covering all four sustainability aspects, data analysis was commenced. First, data preparation, including arranging and entering data onto separate worksheets (coding, categorising and deleting blank responses and so on), was done to ease the data analysis. Four worksheets were prepared to analyse the data separately in line with each sustainability aspect. Data analysis proceeded in accordance with the four worksheets and sustainability aspects. The first part of the analysis was to check the validity of the developed factors on a majority scale of opinions of local councils in Australia. In other words, there were only six local councils previously engaged with the approval of factors. With the responses to the questionnaire covering a wide range of local councils in

Australia, it could be checked whether the approval remained. Average index or weighted arithmetic mean is a useful tool which can be utilised for this case. Therefore, the average index values of factors for all four sustainability aspects were calculated using the following equation.

$$\text{Average Index} = \frac{\sum_{i=1}^{5} a_i * x_i}{\sum_{i=1}^{5} x_i}$$

...............Equation 3.1

where, a_i = constant expressing the weight given to i; a_1=1, a_2=2, a_3=3, a_4=4, a_5=5

x_i = variable expressing the frequency of response for i = 1, 2, 3, 4, 5

All the results with values of more than 3.5 for their average index values related to the Likert scale opinions of “Agree” and “Strongly Agree”. This confirmed the validity of the factors. Therefore, all factors were directed to the next phase of data analysis: factor analysis. A detailed analysis of average index values is presented in Chapter 4.

Factor analysis in this study, adopted the method of principal component analysis with Eigen values greater than one. It was then followed by Varimax rotation with Kaiser Normalization. The data were first checked for the appropriateness of doing factor analysis. During the study, each questionnaire received more than 100 responses (107 responses relating to the environmental, economic and social aspects, and 106 responses to the functional aspect). Also, they were at least four times greater than the number of variables considered (23, 13, 17 and 14 variables for each questionnaire related to environmental, economic, social and functional aspects). Hence, the number of responses captured in the questionnaire fulfills minimum requirements for factor analysis proposed by Hair (1992).

The data were then screened through the correlation matrix to check whether any variable received a majority of significance values with other variables greater than 0.05 (Field, 2009). Next was the scan of correlation coefficients themselves, looking for any greater than 0.9 (Field, 2009). Simultaneously, the determinant of the R-matrix was checked to see whether it was greater than 0.00001 (Field, 2009) to confirm that no extreme multicollinearity existed in the data. Otherwise, one or two variables causing the problem can be eliminated and the analysis can be continued. The analysis continued with checking KMO values for each questionnaire and they were all found to be greater than 0.5. Next, Bartlett’s test was performed and values were obtained for the significance value of R-matrix. They were also less than 0.5; therefore, both tests confirmed the adequacy of the sample and the appropriateness of doing factor analysis, and ultimately the validity of the factors.

The interpretation of the results of factor analysis is governed by the factor loading or suppressed factor, which indicates how the variables are related to the component or factor (Field, 2009). According to Manly (1994), a factor loading of greater than 0.50 is sufficient to interpret the results. On the other hand, Stevens (2009) suggests that the sample size is critical in choosing the factor loading. A factor loading of 0.512 can be used when the number of responses is greater than 100. In this analysis, 0.512 was used for the factor loading due to the number of responses being greater than 100. Labelling of components was finalised based on the opinions of the research group, because there is no objective way to calculate the meanings of components (Cooper, 2011). The idea that higher loading variables represent the components (Hair, 1992) was used for the labelling of some components in this study. The research pinpointed 18 major group factors (henceforth the term “criteria” is used for group factors) to represent all key factors of all sustainability aspects. They included 7 criteria to represent environmental sustainability; 4 criteria for economic sustainability; 4 criteria for social sustainability and 3 criteria for functional sustainability. Table 3.6 illustrates the criteria with the given term under each sustainability aspect. The detailed analysis of all criteria is presented in Chapter 4.

Table 3.6: Criteria used to assess sustainability in four major aspects

Aspect	Criteria
Environmental aspect	1. Water management 2. Material sustainability 3. Energy efficiency 4. Waste management 5. Air and noise pollution 6. User comfort 7. Usage of hazardous goods and materials
Economic aspect	1. Life cycle cost 2. Land value 3. Local economy 4. Additional capital investment
Social aspect	1. Local community engagement 2. Community benefits and equity 3. Neighborhood character 4. Employee well-being
Functional aspect	1. Impact of failure and response 2. Minimum level of service 3. Compliance to building standards and regulations

3.3.6 Development of a comprehensive decision-making hierarchical structure

Based on the factor analysis results, the assessment process for the sustainable management of community buildings was finalised as flowing in three hierarchical levels. The top level of the structure represents the overall sustainability impact of a given building component. It is then broken down to the sustainability impacts of four major aspects: environmental sustainability impact, economic sustainability impact, social sustainability impact and functional sustainability impact. The third and last level of the structure captures the sustainability impact of each criterion caused by the given building component with respect to the relevant sustainability aspect. Figure 3.3 illustrates the hierarchical structure.

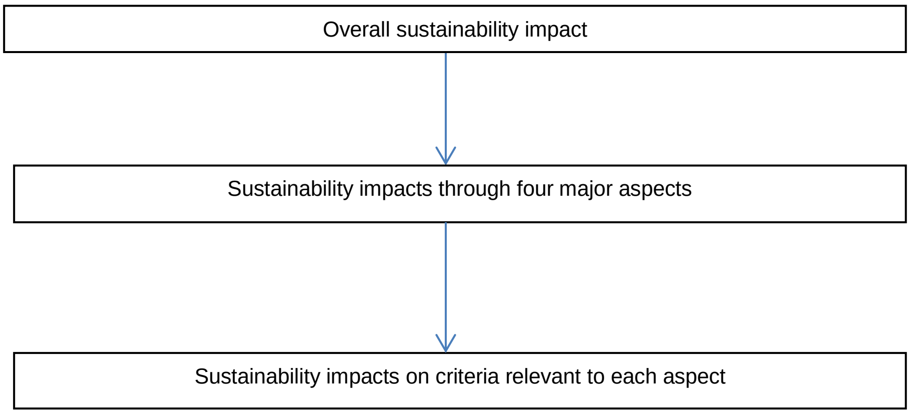


Figure 3.3: Hierarchical decision-making structure for the sustainable management of community buildings

3.3.7 Development of a decision-making model

The development of a decision-making model was designed on the basis of the established hierarchical structure discussed in Section 3.3.6. The evaluation procedure of the model was designed, starting from the bottom level of the hierarchy and continuing to the next levels in two steps. The first step covered the determination of the impact of each sustainability aspect caused by the given building component through the combined effect of their criteria. The second step determined the combined effect of the derived impacts of each sustainability aspect thus that was the overall sustainability impact caused by the given building component.

In terms of the evaluation of the combined impact of the influencing factors, two aspects are important to be considered. The first aspect concerns the weighting of each criterion related to the overall impact on the sustainability aspect as well as the weighting of each sustainability aspect related to the overall sustainability impact. In other words, the extent of the significance of each criterion through the related sustainability aspect has an effect on the impact of the sustainability aspect. Similarly, depending on the level of significance of each sustainability aspect, the impact of the overall sustainability varies. Hence, the sole decider of the weighting is based on the context of the sustainable management of community buildings i.e. the weighting value does not vary according to building component; therefore it is a fixed value for all building components. The analytical hierarchy process (AHP) is one of the best approaches to capturing weighting values, and requires pair-wise comparison data (Cheng and Li, 2001, Kablan, 2004, Elkarmi and Mustafa, 1993). Hence, another industry-wide questionnaire was carried out in order to capture pair-wise comparison data. The detailed description of that questionnaire and the data analysis is covered in Chapter 5.

The second aspect related to impact calculations is the individual impact caused by a given building component by the criteria. For example, building coordinators can assess the individual impact caused by the heating ventilation and air condition (HVAC) system on the criterion of “water management” or “energy efficiency”. The impact assessment is intangible and hence tends to be a subjective decision. The fuzzy linguistic terms associated with a range of numbers and definitions of linguistic terms according to the criteria are the best way to minimise subjectivity. It converts a completely qualitative thing to a somewhat quantitative. The researcher adopted a similar method to assess the impact values, as explained in detail in Chapter 6.

The proposed model was run in two steps as mentioned above. The AHP and simple additive weighting (SAW) method were used in step 1. Step 2 can be run using similar methods as well as a partly Neural fuzzy system application for the evaluation of overall sustainability impact value from the associated four sustainability impact values. Hence, the researcher proposes two models, of which one comprises AHP and SAW. The other model is a combination of AHP, SAW and partly Neuro fuzzy system. Both models are given a detailed explanation in Chapter 6.

3.3.8 Integrated decision-making

Prioritising maintenance activities of building components based on sustainability impact values

The output of the proposed decision-making model interprets sustainability impact of the given building component. Without a score to understand the extent impact, only linguistic terms, even experts struggle to compare building components. Even if they could, they can only compare one aspect of sustainability at a time, so the combined effect of comparisons becomes more complicated. Both issues are diminished with the proposed model by using the generated values and sorting them accordingly. Also, the model gives flexibility to users to not only capture overall sustainability impact values but also the individual impact values of four sustainability aspects. Hence, they can make informed decisions. The method is explained with a numerical illustration in Chapter 8 based on the values obtained in Chapter 7.

Optimising cost of maintenance activities under ongoing deterioration

All local councils have minimum performance conditions for different building components which are to be sustained during the function of the building components. Depending on the impact on the level of service, minimum performance level fluctuates for different building components. In relation to the maintenance of that performance level, ongoing deterioration becomes the main consideration. On the other hand, councils are not capable of allocating the full amount of money to maintain the required performance of every building component for a planned duration. However, councils can adapt to a maintenance system such that more prioritised components can acquire the required level while less prioritised ones will be maintained at lower levels of the expected performance. This will optimise the cost maintaining effective performance of the system and minimising a considerable amount of backlog maintenance. The process uses the probability transition matrix used in the Markov process for deterioration prediction and financial evaluation techniques for cost calculations. A detailed process description is given in Chapter 8.

Determining the best intervention times for whole building assets for renewals during the planned period

Another major aspect in terms of decision-making is to determine the best intervention periods for renewals of whole building assets. In this context, service life is very important and it can be simply explained as the time period over which the asset varies its condition from the best condition to worst condition. Actual useful life is “the period of time after installation during which a building or its parts meet or exceed the performance requirements" according to ISO 15686-1. Accordingly, required performance is "the minimum acceptable level of a critical property" or an "inherent or acquired attribute of a building or a part of a building that has an acceptable value of its required function which is to be fulfilled" (ISO 15686-1) cited in (McDulling, 2006). The main tool for monitoring service life is the deterioration prediction curve of the asset. Hence, the present study assumed the curve is provided for the decision-making aspect. According to the curve and some attribute variables, the current study proposes a method to determine the best intervention times for renewals of whole building assets during the planned period. The method is explained in detail in Chapter 8.

3.3.9 Development of Council Asset Management Software (CAMS)

For use by the end-users of this industrial project, a user-friendly web-based software tool has been generated to aggregate the outcomes of this project. The program has in-built default features as well as features with a high level of flexibility to map the user experience. The inventory data has the ability of being either manually entered or imported via spread sheets. Several modules have been developed under the main software to provide support with asset maintenance, asset management, asset long-term planning, and strategies. The algorithms of modules in the software are presented in Chapter 9.

3.4 Concluding Remarks

This chapter has provided a detailed description of the methodological approach adopted in the research, while appropriately addressing the research questions and achieving the set objectives. The researcher consulted relevant research literature to address methodological issues as well as learn of current practices in the industry to identify gaps in knowledge. Both results were amalgamated in the design of the research process. Two industry-wide questionnaires were undertaken and data analysis was done based on the responses. Specific analytical tools (AHP and Neuro fuzzy systems) were incorporated in the development of the decision-making model, followed by three integrated decision-makings connected with the sustainable management of community buildings. Finally, the chapter concludes with the development of a council asset management software, which is the final outcome anticipated from the main industrial project.

4 ESTABLISHMENT OF FACTORS INFLUENCING DECISION-MAKING IN THE SUSTAINABLE MANAGEMENT OF COMMUNITY BUILDINGS

4.1 Introduction

This chapter presents the data analysis and findings according to the responses to this questionnaire. The analysis used mathematical equations to calculate average index values and factor analysis. All analysis related to factor analysis was conducted using SPSS software (IBM, 2013). The findings contributed to the development of a comprehensive decision-making hierarchical structure.

4.2 Purpose of Industry-wide questionnaire 1

The questionnaire had the following objectives:

1. Further check of validity of the key factors (already validated by partner councils) based on a majority of opinions of local councils in Australia
2. Refinement of key factors using factor analysis, based on the questionnaire responses

4.3 Data Collection

> *The population refers to the entire group of people, events or things of interest for which the researcher wishes to investigate (Sekaran and Bougie, 2010).*

A sample of the population is used in most surveys due to the existence of large amounts of data in the population and the practical impossibility of collecting all of them (Sekaran and Bougie, 2010). In this study, the sample needed to be selected from a specific target group, local council professionals who engage in building management practice. Hence, the type of sampling used in the study was purposive sampling. The rationale for the selection of the target group was that they were the only ones who could provide desired information conformed to the criteria set in the research. The sample type can be further categorised as “judgement sampling” because the subjects of the sample, who were experts in the field, were advantageously placed or in the best position to provide the information required.

There are 564 local councils in Australia in total, but 267 local councils gave consent to take part in the survey. The survey received 115 responses addressed to each sustainability aspect. Even at 115 responses, only 107 responses under the environmental aspect were complete, and a similar situation applied for the economic and social aspects. 106 complete responses were obtained for the functional aspect. Given that the number of responses considered was 106, the response rate was 39.70% (>30%), which is an acceptable outcome to represent the sample (Sekaran and Bougie, 2010).

4.4 Data Reliability

As Section 3.3.4 suggested, Cronbach's Alpha was used to test the reliability of the responses of the questionnaire. The value of Cronbach's Alpha coefficient (α) can be computed using the following equation;

$$\propto = \frac{k}{k-1}\left[1 - \frac{\sum s_i^2}{s_i^2}\right]$$

..............Equation 4..1:

where,

α = Cronbach's alpha,

K = Number of items in the questionnaire and,

$\sum s_i^2$ = Sum of variance of each item's score

The reliability of responses to the four aspects was checked separately using SPSS software and the results are shown in Table 4.1. The results indicate that all sets of response data related to each aspect exhibit acceptable reliability (Nunnally, 1975, Hinton et al., 2004).

Table 4.1: Data reliability analysis (Cronbach's alpha results)

Aspect of the questionnaire	Reliability coefficient (α)
Environmental aspect	0.893
Economic aspect	0.843
Social aspect	0.882
Functional aspect	0.896

4.5 Identification of key factors based on majority opinions of local councils in Australia

As previously stated, average index was the main tool utilized for this task. In this case, a Likert scale classification was used to capture responses, as shown in Table 4.2.

Table 4.2: Likert scale classification

Likertscale	Absolute value	Value range
Strongly disagree	1	1.00 < Value < 1.50
Disagree	2	1.50 ≤ Value < 2.50
Neither agree nor disagree	3	2.50 ≤ Value < 3.50
Agree	4	3.50 ≤ Value < 4.50
Strongly agree	5	4.50 ≤ Value < 5.00

Each environmental factor attracted responses from 107 local councils in Australia. The way of distribution of those responses according to Likert scale is shown in Table 4.3. The table also shows calculated average index values for environmental factors pertinent to the frequency of Likert scale opinions. Equation 3.1 was utilized in the calculation of average index values. According to Table 4.2, values on the Likert scale equal to or greater than 3.5 indicate the range of agreement with "Agree" and "Strongly Agree", which represents hundred per cent confidence of the validity of that factor. The values shown in Table 4.3 also fall in the range of average index values. Hence, all environmental factors were validated by the majority opinions of local councils in Australia.

A similar process was adopted to check the validity of factors pertinent to other aspects. The distribution of opinions received is displayed in tabular form in Tables 4.4, 4.5 and 4.6 for the rest of the aspects. An average index of each factor was calculated according to the frequency of opinions obtained for each Likert scale and accompanies the table. According to these figures, all average index values exceed 3.5. Therefore, each factor was validated by a majority of the opinions of Australian local councils.

Table 4.3: Distribution of response data and analysis results of the validity check of environmental factors

Description of the factor	Strongly Disagree	Disagree	Agree nor Disagree	Agree	Strongly agree	Total	Average Index	Key factor is validated or not
Reduction of GHG (Green House Gas) emission	1	4	22	51	29	107	3.96	YES
Amount of noise pollution	0	6	34	59	8	107	3.64	YES
Amount of air pollution	1	3	24	61	18	107	3.85	YES
The amount of green energy consumption	1	7	29	53	17	107	3.72	YES
The amount of energy consumption	0	2	6	43	56	107	4.42	YES
The amount of used materials with low embodied energy	1	9	41	48	8	107	3.50	YES
Impact on energy use	0	3	12	69	23	107	4.05	YES
Lighting efficiency	0	1	6	47	53	107	4.42	YES
Sourcing materials locally	1	6	36	37	27	107	3.77	YES
Building reuse	0	2	32	49	24	107	3.88	YES
Cyclist facilities	1	10	33	52	11	107	3.58	YES
Use of rain water	1	5	12	56	33	107	4.07	YES
Recycling of grey water	1	9	24	53	20	107	3.77	YES
Impact on quality storm water run-off	1	5	17	62	22	107	3.92	YES
Impact on potable water use	1	6	30	50	20	107	3.77	YES
Thermal comfort	0	2	15	59	31	107	4.11	YES
Indoor air quality	0	1	13	68	25	107	4.09	YES
Impact on air quality	1	3	17	66	20	107	3.94	YES
Usage of hazardous goods and materials (e.g. asbestos)	7	4	8	32	56	107	4.18	YES

Refurbishment of noise and pollution	0	4	43	51	9	107	3.60	YES
Usage of recycled materials	0	5	36	54	12	107	3.68	YES
Construction waste management	0	5	20	68	14	107	3.85	YES
Operation waste management	0	3	14	64	26	107	4.06	YES

Table 4.4: Distribution of response data and analysis results of the validity check of economic factors

Description of the factor	Strongly Disagree	Disagree	Agree nor Disagree	Agree	Strongly agree	Total	Average Index	Key Factor is validated or not
Additional capital investment cost	0	1	14	55	37	107	4.19	YES
Maintenance and renewal cost	0	0	4	37	66	107	4.57	YES
Replacement cost	1	0	10	48	48	107	4.32	YES
Operation cost	0	0	6	51	50	107	4.41	YES
Residual value including land value	1	5	41	42	18	107	3.66	YES
Routine maintenance cost	0	0	7	54	46	107	4.36	YES
Local employment opportunity	0	7	26	58	16	107	3.77	YES
Use of local materials and local suppliers	0	5	29	58	15	107	3.77	YES
Revenue generation for the council	2	7	29	48	21	107	3.73	YES
Community land value (Depending on the current market value)	2	9	44	37	15	107	3.50	YES
small business advancement in the local government area	0	7	30	58	12	107	3.70	YES
Tourism significance	0	10	37	50	10	107	3.56	YES
Minimising life cycle costs	0	1	7	40	59	107	4.46	YES

Table 4.5: Distribution of response data and analysis results of the validity check of social factors

Description of the factor	Strongly Disagree	Disagree	Agree nor Disagree	Agree	Strongly Agree	Total	Average Index	Key Factor is validated or not
Equity of employees	0	6	29	56	16	107	3.76	YES
Equity of users	0	2	13	66	26	107	4.08	YES
Provision of recreational and essential facilities	0	1	3	64	39	107	4.32	YES
Accessibility	0	1	1	43	62	107	4.55	YES
Community's health/well-being (The hygienic condition)	0	1	7	57	42	107	4.30	YES
Feeling of security	0	0	12	62	33	107	4.19	YES
Impact on healthy life style	0	1	8	68	30	107	4.18	YES
Usage of hazardous goods and materials	5	3	17	47	35	107	3.97	YES
Heritage value of the building	1	3	24	52	27	107	3.94	YES
Image of the council	0	2	11	55	39	107	4.22	YES
Aesthetics	0	1	11	72	23	107	4.09	YES
Local community involved	0	2	11	60	34	107	4.17	YES
Local community expectation	0	2	9	66	30	107	4.15	YES
Local community support	0	3	11	60	33	107	4.15	YES
Level of community demand	0	1	5	63	38	107	4.28	YES
Number of community members that will benefit	0	2	9	55	41	107	4.26	YES
Proximity via public transport, cycling, walking	1	3	20	58	25	107	3.96	YES

Table 4.6: Distribution of response data and analysis results of the validity check of functional factors

Description of the factor	Strongly Disagree	Disagree	Agree nor Disagree	Agree	Strongly Agree	Total	Average Index	Key Factor is validated or not
Number of users affected due to failure	0	2	7	60	37	106	4.24	YES
Severity of failure	0	1	9	52	44	106	4.31	YES
Length of interruption to service	0	1	5	59	41	106	4.32	YES
Availability of alternative resources	0	1	17	60	28	106	4.08	YES
Adaptability of users to a proposed change	0	2	29	58	17	106	3.84	YES
Likelihood of failure	0	1	17	59	29	106	4.09	YES
Facilities and services management	0	0	12	66	28	106	4.15	YES
Minimum acceptable level of service	0	1	9	59	37	106	4.24	YES
Accountability to users	0	1	17	64	24	106	4.04	YES
The ability to meet short term demands	0	1	19	66	20	106	3.99	YES
The ability to meet long term demands	0	2	8	61	35	106	4.21	YES
Compliance to the Building Code	0	0	4	38	64	106	4.56	YES
Compliance to the OHS standards	0	0	1	36	69	106	4.64	YES
Compliance to disability	0	0	1	39	66	106	4.61	YES

4.6 Factor analysis of key factors

Principle component analysis is used to extract the similar characteristic groups out of the key factors in which the central concept is the summarization of key factors by a smaller set of factors. In other words, a larger set of key factors is represented by a smaller set of factor groups. Henceforth, the term “factor groups” is replaced by “criteria”. As Sections 3.3.4 and 3.3.5 explained, sample size was checked based on the variables existing in the problem prior to factor analysis. Two recommendations suggested by Hair (1992) were adopted for the selection of an adequate number of responses. The selection considered obtaining responses from at least four to five times the number of variables in the problem and the number of total responses should be no fewer than 50 but more than 100 is preferable (Hair, 1992).

The software Statistical Package for the Social Sciences (SPSS), Version 19 aided the execution of the factor analysis. The analysis followed four major stages as follows:

- Stage 1: Preliminary analysis
- Stage 2: Factor extraction
- Stage 3: Factor rotation and interpretation
- Stage 4: Reliability analysis on derived factors

<u>Stage 1: Preliminary analysis</u>

> *SPSS will nearly always find a factor solution to a set of variables. However, the solution is unlikely to have any real meaning if the variables analysed are not sensible. (Field, 2005).*

The above idea does not deliver that data screening is necessarily required for factor analysis. However better results with real meanings may be generated with data screening. According to Field (2005), variables that have fewer correlations with other variables are better to be excluded before the factor analysis is run. In contrast, extreme multicollinearity (i.e. variables that are highly correlated) and singularity (variables that are perfectly correlated) are important to be avoided in the data set for factor analysis (Field, 2005).

Stage 1 was for data screening and several options statistically available were utilised for this purpose. The output of correlation matrix, which is the abridged version of R-matrix, is the main source exploited in those options. The top half of the table contains the Pearson correlation coefficients between all pairs of variables, whereas the bottom half contains the one-tailed significance of these coefficients. The check first scans the significance values looking for any variable for which the majority of values are greater than 0.05. A simultaneous check is carried out to scan the correlation coefficients themselves looking for any greater than 0.9. If any are found, that indicates a problem that could arise due to singularity. This can be more confidently verified on the basis of the determinant of the correlation matrix. The threshold value of the determinant is 0.00001. Hence, problems with the determinant value of less than the threshold value require elimination of variables according to the above checks for multicollinearity. However, Haitovsky (1969) proposed the contradictory idea of using a significance test when the determinant is zero (i.e. the matrix is singular). According to him, if, the test is significant, it means that the correlation matrix is significantly different from a singular matrix, which implies that there is no severe multicollinearity.

The next phase of Stage 1 was the further checking of sample adequacy for factor analysis. The Kaiser-Meyer-Olkin (KMO) measure of sampling interprets the state of adequacy of the sample (Field, 2009) and indicates sufficient inter-correlations for doing factor analysis (Hair, 1992). The KMO statistic varies between 0 and 1, and 0 creates a situation that the sum of partial correlations is large relative to the sum of correlations. This is an indication of diffusion in the pattern of correlations; hence, this gives rise to factor analysis inappropriate.

The opposite is also true, that KMO values closer to 1 indicate that patterns of correlations are relatively compact, so factor analysis should yield distinct and reliable factors. Kaiser (1974) makes the generic recommendation that a KMO value of greater than 0.5 is barely acceptable for doing a factor analysis, whereas Hutcheson and Sofroniou (1999) give detailed ranges for acceptability levels. These acceptability levels and the related range of KMO values are given in Table 4.7.

Table 4.7: KMO value ranges and their related acceptability levels for the adequacy of sample for factor analysis

KMO value range	Acceptability level
0.5 – 0.7	Mediocre
0.7 – 0.8	Good
0.8 – 0.9	Great
Above 0.9	Superb

The last test before moving to Stage 2 was to carry out Bartlett's test of sphericity, which examines whether the correlation matrix resembles an identity matrix. If the correlation matrix resembles an identity matrix, it means that every variable correlates very badly with all other variables (i.e. all correlation coefficients are close to zero) (Field, 2009). If it was an identity matrix then it would mean that all variables are perfectly independent from one another (all correlation coefficients are zero) (Field, 2009). These problematic scenarios create no clusters out of the variables. Hence, prior knowledge of whether the correlation matrix is significantly different from an identity matrix, which is shown by Bartlet's test, is very important in the preliminary stage of factor analysis. If the significance value given by the Bartlet's test is less than 0.5, it is highly appropriate to continue factor analysis (Pallant, 2007).

Stage 2: Factor extraction

Factor extraction involves determining the smallest number of factors that can be used to best represent the interrelations among the set of variables (Pallant, 2007). There are several ways of extracting factors including the following:

- Principal components
- Unweighted least squares
- Generalized least squares
- Maximum likelihood
- Principal axis factoring
- Alpha factoring
- Image factoring

The method is chosen depending on the ambitions behind the analysis. According to Tinsley and Tinsley (1987), there are two things to consider in choosing which method to use for extracting factors. They are: whether the study wants to generalise the findings from the sample to a population, or whether the study explores data or tests a specific hypothesis. Some techniques of factor analysis are applied to the entire population of interest. Therefore, certain techniques, including principal component analysis, assume that the sample used is the population, and so results cannot be extrapolated beyond that particular sample (Pallant, 2007). All the requirements for selections are matched. Hence, the current study adopted principal component analysis, which is the most commonly used approach in practice (Pallant, 2007).

The extraction is mainly done on the basis of the Eigen value. According to Kaiser's criterion, only factors with an Eigen value of 1.0 or more are retained for further investigation. The Eigen value of a factor represents the amount of the total variance explained by the factor. Catell's Scree plot is another approach used to assist in the decision concerning the number of factors to retain (Cattell, 1966). This involves plotting each of the Eigen values of the factors and inspecting the plot to find a point at which the shape of the curve changes direction and becomes horizontal. The default method used in SPSS is the former one. However, the final decision has to be made looking at the results of both methods. There are two criteria available for this purpose (Field, 2005):

- If there are less than 30 variables and communalities after extraction are greater than 0.7 or if the sample size exceeds 250 and the average communality is greater than 0.6, then retain all factors with Eigen values above 1 (Kaiser's criterion)
- If none of the above apply, a scree plot can be used when the sample size is large (around 300 or more)

<u>Stage 3: Factor rotation and interpretation</u>

The purpose of the rotation is to improve the interpretability of factors. Rotation maximizes the loading of each variable on one of the extracted factors whilst minimizing the loading on all other factors (Field, 2005). Rotation works by changing the absolute values of the variables whilst keeping their differential values constant (Field, 2005). There are two main approaches to rotation: orthogonal and oblique. Orthogonal rotations are required when the factors are independent, whereas oblique rotations are the preferable method when the factors are correlated. Within the two broad categories of rotational approaches; Varimax, Quarimax and Equimax are orthogonal rotations, while Promax, Direct and Oblimin are oblique rotations. The problem investigated in the current study requires analysis aided with orthogonal rotation. Therefore the researcher chose Varimax orthogonal rotation, which is the most commonly used (Pallant, 2007) and recommended (Field, 2005), and capable of minimising the number of variables that have high loadings on each factor.

Factor loadings are a gauge of the substantive importance of a given variable to a given factor. The rotated component matrix shows factor loadings for each variable onto each factor after rotation, provided that only the values above the selected suppressed factor loading are displayed. Suppressed factor loading decides the threshold value of the factor loadings of variables significant to the factor. Typically, researchers take a loading of an absolute value of 0.3 to be significant (Field, 2009). According to Manly (1994), a factor loading of greater than 0.50 is sufficient to interpret the results. However, the significance of a factor loading will depend on the sample size (Stevens, 2009). Accordingly, Stevens formulated the following table (Table 4.8) providing critical values of factor loadings compared with the sample size. Hence, the current study chose 0.512 as the suppressed factor loading, because the number of responses obtained was slightly more than 100.

Table 4.8: Critical factor loading values compared with the sample size

Sample size	Suppressed factor loading value
50	0.722
100	0.512
200	0.364
300	0.298
600	0.210
1000	0.162

The final result based on the selected suppressed value will give the factor solution for the problem, and will display all the factors with underlying variables. Hence, meaningful interpretations must be assigned to factors by looking at underlying variables. In this case, a degree of inventiveness and imagination is required for the factor labelling process. However, names can differ depending on the analyst due to different background and training, making the process subjective (Hair, 1992). Moreover, there is no particular method, but it can be performed according to the idea that variables with higher loadings have a great influence on the name to represent a factor. In some factor analysis, all the variables may not be represented by factors; some variables below the suppressed factor loading may be ignored. Ignoring the variables may be appropriate if the objective is solely data reduction (Hair, 1992). The researcher sought the study team's opinion for labelling the factors to minimise subjectivity.

Stage 4: Reliability analysis on derived factors

Cronbach's α is a reliability coefficient that reflects how well the items in a set are positively correlated to one another (a detailed description of Cronbach's α is given in Section 3.3.4). The cut-off points and correlated reliabilities are also stated in Section 3.3.4. 0.70 is the most acceptable level, however Sekaran and Bougie (2010) state that acceptability can still exist for data when the alpha is over 0.60. Cronbach (1951) suggested that if several factors exist then the formula that calculates α should be applied separately to items relating to different factors. In other words, a questionnaire can be regarded as comprised of sub-scales, so the formula is applied separately to sub-scales. A similar process was used for the derived factors to test the reliability of variables for the factor.

4.6.1 Factor analysis results of environmental key factors

Stage 1: Preliminary analysis

Variables used for the analysis were key factors of environmental sustainability and they were represented by the codes En1, En2… En23, as shown in Table 3.1.The first output of this analysis was the table of the correlation matrix. The output shows the correlation coefficient and one-tailed significance data of all pairs after eliminating variables with multicollinearity. With all variables, the determinant of the correlation matrix was found to be less than 0.00001. Therefore, the significance data were scanned and the majority of values greater than 0.05 were related to one variable or more. Simultaneously, their correlation coefficients were checked to see whether there was any greater than 0.9. The scan results suggested that En10 was most probably the cause for the determinant being less than 0.00001. Hence, it was eliminated. SPSS was re-run with amended variables and the output of its correlation matrix is shown in Table 4.9. The determinant was 0.0000135, and it therefore fulfilled the first criterion for assessing the appropriateness of factor analysis.

Table 4.9: Output 1: Correlation Matrix

Correlation Matrix[a]

		En1	En2	En3	En4	En5	En6	En7	En8	En9	En11	En12	En13	En14	En15	En16	En17	En18	En19	En20	En21	En22	En23
Correlation	En1	1.000	.136	.360	.370	.433	.295	.305	.340	.230	.364	.272	.253	.262	.275	.308	.168	.465	.182	.055	.315	.214	.307
	En2	.136	1.000	.613	.218	.084	.284	.298	.145	.224	.273	.303	.199	.238	.253	.119	.356	.343	-.131	.386	.272	.429	.348
	En3	.360	.613	1.000	.162	.207	.258	.350	.122	.278	.383	.331	.288	.404	.314	.118	.268	.560	-.036	.341	.292	.299	.336
	En4	.370	.218	.162	1.000	.333	.330	.445	.334	.260	.386	.285	.344	.433	.331	.195	.103	.158	.001	.106	.256	.380	.267
	En5	.433	.084	.207	.333	1.000	.176	.348	.482	.242	.137	.190	.228	.283	.092	.366	.126	.178	.034	.001	.049	.076	.205
	En6	.295	.284	.258	.330	.176	1.000	.260	.400	.179	.431	.243	.354	.387	.368	.305	.402	.403	-.035	.270	.548	.391	.188
	En7	.305	.298	.350	.445	.348	.260	1.000	.350	.155	.189	.130	.147	.292	.219	.311	.263	.275	.175	.366	.127	.300	.340
	En8	.340	.145	.122	.334	.482	.400	.350	1.000	.239	.314	.292	.256	.374	.197	.393	.254	.189	.064	.140	.185	.288	.241
	En9	.230	.224	.278	.260	.242	.179	.155	.239	1.000	.353	.292	.419	.463	.340	.198	.020	.396	.047	.301	.380	.298	.239
	En11	.364	.273	.383	.386	.137	.431	.189	.314	.353	1.000	.290	.350	.476	.337	.257	.294	.436	.128	.313	.379	.441	.283
	En12	.272	.303	.331	.285	.190	.243	.130	.292	.292	.290	1.000	.625	.449	.490	.146	.187	.284	.025	.100	.255	.279	.301
	En13	.253	.199	.288	.344	.228	.354	.147	.256	.419	.350	.625	1.000	.710	.589	.284	.280	.427	-.033	.263	.436	.416	.296
	En14	.262	.238	.404	.433	.283	.387	.292	.374	.463	.476	.449	.710	1.000	.584	.334	.318	.522	-.016	.320	.362	.488	.347
	En15	.275	.253	.314	.331	.092	.368	.219	.197	.340	.337	.490	.589	.584	1.000	.232	.379	.354	.072	.352	.498	.432	.386
	En16	.308	.119	.118	.195	.366	.305	.311	.393	.198	.257	.146	.284	.334	.232	1.000	.535	.357	.162	.340	.215	.188	.332
	En17	.168	.356	.268	.103	.126	.402	.263	.254	.020	.294	.187	.280	.318	.379	.535	1.000	.443	.043	.390	.334	.293	.270
	En18	.465	.343	.560	.158	.178	.403	.275	.189	.396	.436	.284	.427	.522	.354	.357	.443	1.000	.146	.452	.489	.369	.299
	En19	.182	-.131	-.036	.001	.034	-.035	.175	.064	.047	.128	.025	-.033	-.016	.072	.162	.043	.146	1.000	.135	.068	.139	.282
	En20	.055	.386	.341	.106	.001	.270	.366	.140	.301	.313	.100	.263	.320	.352	.340	.390	.452	.135	1.000	.546	.538	.375
	En21	.315	.272	.292	.256	.049	.548	.127	.185	.380	.379	.255	.436	.362	.498	.215	.334	.489	.068	.546	1.000	.569	.329
	En22	.214	.429	.299	.380	.076	.391	.300	.288	.298	.441	.279	.416	.488	.432	.188	.293	.369	.139	.538	.569	1.000	.695
	En23	.307	.348	.336	.267	.205	.188	.340	.241	.239	.283	.301	.296	.347	.386	.332	.270	.299	.282	.375	.329	.695	1.000

Sig. (1-tailed)	En1		.081	.000	.000	.000	.001	.001	.000	.008	.000	.002	.004	.003	.002	.001	.042	.000	.030	.287	.000	.013	.001
	En2	.081		.000	.012	.194	.002	.001	.068	.010	.002	.001	.020	.007	.004	.111	.000	.000	.089	.000	.002	.000	.000
	En3	.000	.000		.048	.016	.004	.000	.106	.002	.000	.000	.001	.000	.001	.113	.003	.000	.356	.000	.001	.001	.000
	En4	.000	.012	.048		.000	.000	.000	.000	.003	.000	.001	.000	.000	.000	.022	.146	.052	.494	.138	.004	.000	.003
	En5	.000	.194	.016	.000		.035	.000	.000	.006	.080	.025	.009	.002	.172	.000	.099	.033	.365	.496	.309	.218	.017
	En6	.001	.002	.004	.000	.035		.003	.000	.033	.000	.006	.000	.000	.000	.001	.000	.000	.359	.002	.000	.000	.026
	En7	.001	.001	.000	.000	.000	.003		.000	.055	.026	.091	.065	.001	.012	.001	.003	.002	.036	.000	.095	.001	.000
	En8	.000	.068	.106	.000	.000	.000	.000		.007	.001	.001	.004	.000	.021	.000	.004	.026	.257	.075	.028	.001	.006
	En9	.008	.010	.002	.003	.006	.033	.055	.007		.000	.001	.000	.000	.000	.020	.417	.000	.316	.001	.000	.001	.007
	En11	.000	.002	.000	.000	.080	.000	.026	.001	.000		.001	.000	.000	.000	.004	.001	.000	.095	.001	.000	.000	.002
	En12	.002	.001	.000	.001	.025	.006	.091	.001	.001	.001		.000	.000	.000	.066	.027	.002	.397	.153	.004	.002	.001
	En13	.004	.020	.001	.000	.009	.000	.065	.004	.000	.000	.000		.000	.000	.002	.002	.000	.368	.003	.000	.000	.001
	En14	.003	.007	.000	.000	.002	.000	.001	.000	.000	.000	.000	.000		.000	.000	.000	.000	.434	.000	.000	.000	.000
	En15	.002	.004	.001	.000	.172	.000	.012	.021	.000	.000	.000	.000	.000		.008	.000	.000	.232	.000	.000	.000	.000
	En16	.001	.111	.113	.022	.000	.001	.001	.000	.020	.004	.066	.002	.000	.008		.000	.000	.048	.000	.013	.026	.000
	En17	.042	.000	.003	.146	.099	.000	.003	.004	.417	.001	.027	.002	.000	.000	.000		.000	.332	.000	.000	.001	.002
	En18	.000	.000	.000	.052	.033	.000	.002	.026	.000	.000	.002	.000	.000	.000	.000	.000		.067	.000	.000	.000	.001
	En19	.030	.089	.356	.494	.365	.359	.036	.257	.316	.095	.397	.368	.434	.232	.048	.332	.067		.083	.245	.076	.002
	En20	.287	.000	.000	.138	.496	.002	.000	.075	.001	.001	.153	.003	.000	.000	.000	.000	.000	.083		.000	.000	.000
	En21	.000	.002	.001	.004	.309	.000	.095	.028	.000	.000	.004	.000	.000	.000	.013	.000	.000	.245	.000		.000	.000
	En22	.013	.000	.001	.000	.218	.000	.001	.001	.001	.000	.002	.000	.000	.000	.026	.001	.000	.076	.000	.000		.000
	En23	.001	.000	.000	.003	.017	.026	.000	.006	.007	.002	.001	.001	.000	.000	.000	.002	.001	.002	.000	.000	.000	

a. Determinant = 1.35E-005

Output 2 followed further checks for assessing the appropriateness of factor analysis. In this regard, the values of the KMO measure of sampling adequacy and Bartlett's test of sphericity were checked. Table 4.10 shows the values of both criteria. According to its values, the KMO measure of sampling adequacy (0.807) was beyond the minimum requirement (0.5) (Kaiser, 1974) and it also falls into the range of being "great" (Hutcheson and Sofroniou, 1999). On the other hand, Bartlett's test of sphericity test shows 0.000 significance value which is less than 0.05. Hence, R matrix is not an identity matrix but significant. Therefore, factor analysis is appropriate to be applied here.

Table 4.10: Output 2: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.807
Bartlett's Test of Sphericity	Approx. Chi-Square	1097.269
	df	231
	Sig.	.000

<u>Stage 2: Factor extraction</u>

SPSS output 3 lists the Eigen values with each linear component (factor) before extraction, after extraction and after rotation. The first three columns under Initial Eigen values show Eigen values, percentage variance of Eigen values and cumulative percentage of variance respectively. Under the next section of Extraction Sums of Squared Loadings, the results of a number of extracted factors are shown, where the first column displays the Eigen values of extracted factors, and the second and third columns of the section show the results of variance individually and cumulatively. The last section, Rotation Sums of Squared Loadings, provides the details of extracted factors after rotation. The details show their Eigen values, percentage of variance of each factor and the cumulative percentage of variance. According to Table 4.11, SPSS extracted seven factors for which Eigen values were greater than 1 by applying the Kaiser criterion.

Table 4.11: Output 3: Total variance explained

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.346	33.389	33.389	7.346	33.389	33.389	3.133	14.242	14.242
2	1.858	8.446	41.834	1.858	8.446	41.834	2.551	11.593	25.836
3	1.625	7.387	49.222	1.625	7.387	49.222	2.533	11.512	37.348
4	1.319	5.996	55.218	1.319	5.996	55.218	2.172	9.873	47.221
5	1.268	5.764	60.982	1.268	5.764	60.982	2.014	9.154	56.375
6	1.118	5.080	66.062	1.118	5.080	66.062	1.842	8.374	64.749
7	1.036	4.707	70.769	1.036	4.707	70.769	1.325	6.021	70.769
8	.909	4.132	74.901						
9	.751	3.415	78.316						
10	.705	3.204	81.520						
11	.627	2.850	84.369						
12	.534	2.428	86.798						
13	.443	2.013	88.810						
14	.427	1.940	90.751						
15	.408	1.852	92.603						
16	.368	1.672	94.275						
17	.301	1.367	95.642						
18	.248	1.128	96.769						
19	.234	1.065	97.835						
20	.173	.787	98.622						
21	.169	.769	99.391						
22	.134	.609	100.000						
Extraction Method: Principal Component Analysis.									

SPSS can also be used to perform the scree test, another method which can be used to extract factors. Output 4 shows the scree plot which depicts the graph of Eigen value vs. Component number two-dimensionally (Figure 4.1). The point of inflection can be first noticed at component number four but there is another drop after component number five. Similarly, another major drop is at nine and after that at 13 and then the plot continues to tail off. Hence, the curve is difficult to interpret whether the study has four factors, five factors, nine factors or thirteen factors.

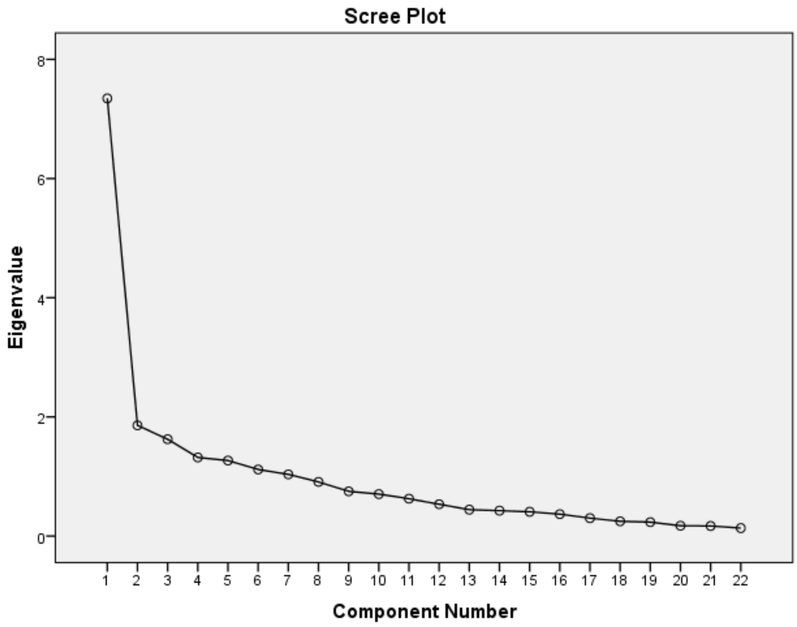


Figure 4.1: Output 4: Scree Plot

Based on two grounds, analysts can come to a judgement whether they use the Kaiser criterion or scree plot (Field, 2009):

- If there are less than 30 variables and communalities after extraction are greater than 0.7 or if the sample size exceeds 250 and the average communality is greater than 0.6 then retain all factors with Eigen values above 1 (Kaiser's criterion)

- If none of the above apply, a scree plot can be used when the sample size is large (around 300 or more cases)

Although the current problem obviously belongs to the Kaiser criterion (because a scree plot is very complex to interpret), the outputs are decided by the two grounds mentioned above. Output 5 (Table 4.12) was utilised for this case and it shows the communality data initially and after extraction. According to the extracted communality data, average communality is greater than 0.6. The sample size does not exceed 250, nonetheless the combined effect based on average communality value and the number of variables (less than 30) disposes the analysis in favour of the Kaiser criterion.

Table 4.12: Output 5: Communalities

Communalities		
	Initial	Extraction
En1	1.000	.680
En2	1.000	.786
En3	1.000	.844
En4	1.000	.701
En5	1.000	.678
En6	1.000	.721
En7	1.000	.637
En8	1.000	.613
En9	1.000	.483
En11	1.000	.545
En12	1.000	.672
En13	1.000	.811
En14	1.000	.701
En15	1.000	.644
En16	1.000	.751
En17	1.000	.787
En18	1.000	.792
En19	1.000	.755
En20	1.000	.670
En21	1.000	.742
En22	1.000	.818
En23	1.000	.737
Extraction Method: Principal Component Analysis.		

<u>Stage 3: Factor rotation and interpretation</u>

Un-rotated component matrix is the next important output (Output 6) before the rotation is applied. Table 4.13 is the related output for the component matrix before rotation, and contains the loadings of each variable onto each factor. By default, it will display all loadings. However, it shows only the loadings above 0.512 because the suppressed factor loading was chosen as 0.512. On the grounds that sample size is more than 100, the study selected 0.512 as the suppressed factor loading (Stevens, 2009).

Table 4.13: Output 6: Un-rotated Component Matrix

Component Matrix[a]							
	Component						
	1	2	3	4	5	6	7
En14	.750						
En22	.700						
En18	.695						
En13	.679						
En15	.671						
En21	.656						
En11	.634						
En6	.609						
En23	.606						
En3	.590			-.578			
En20	.576						
En12	.550						
En17	.540				-.536		
En1	.532						
En4	.531						
En9	.529						
En16	.513						
En7							
En5		.699					
En8		.527					
En2	.521			-.587			
En19				.553			
Extraction Method: Principal Component Analysis.							
a. 7 components extracted.							

The study applied orthogonal rotation for the problem because factors are independent and not correlated with one another. Output 7 is shown in Table 4.14 which represents the rotated component matrix. According to the table, some features are visible. For example, En 9 is not compiled in any factor (due to the suppressed factor being 0.512) and En 19 is the only variable representing Factor 7 (depending on the context of the problem).

Table 4.14: Rotated Component Matrix

Rotated Component Matrix ENVIRONMENTAL[a]							
	Component						
	1	2	3	4	5	6	7
En13	.850						
En12	.777						
En14	.699						
En15	.678						
En9							
En21		.746					
En6		.685					
En11		.605					
En5			.773				
En8			.681				
En4			.611				
En7			.557				
En1			.554				
En22				.741			
En23				.694			
En20				.527			
En3					.858		
En2					.677		
En18					.553		
En17						.814	
En16						.727	
En19							.829

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 9 iterations.

The next step is to interpret the factors by looking at their variables. Table 4.15 gives a clear interpretation of factors looking at their associated variables and the loadings of those variables. Factor or component here is translated to criterion according to the context of the problem investigated in the present study.

Table 4.15: Factor interpretation

Component (or Criterion) number	Interpreted component	Variables (or key factors in this study)	Factor loading
1	Water management	Recycling of grey water (En13)	0.850
		Use of rain water (En12)	0.777
		Impact on quality storm water run-off (En14)	0.699
		Impact on potable water use (En15)	0.678
2	Material sustainability	Usage of recycled materials (En21)	0.746
		The amount of used materials with low embodied energy (En6)	0.685
		Cyclist facilities (En11)	0.605
3	Energy efficiency	The amount of energy consumption (En5)	0.773
		Lighting efficiency (En8)	0.681
		The amount of green energy consumption (En4)	0.611
		Impact on energy use (En7)	0.557
		Reduction of GHG (Green House Gas) emission (En1)	0.554
4	Waste management	Construction waste management (En22)	0.741
		Operation waste management (En23)	0.694
		Refurbishment of noise & pollution (En20)	0.527
5	Air and noise pollution	Amount of air pollution (En3)	0.858
		Amount of noise pollution (En2)	0.677
		Impact on air quality (En18)	0.533
6	User comfort	Indoor air quality (En17)	0.814
		Thermal comfort (En16)	0.727
7	Usage of hazardous goods and materials	Usage of hazardous goods and materials (e.g. asbestos) (En19)	0.829

Stage 4: Reliability analysis on derived factors

The reliability of each factor is tested by calculating the Cronbach's alpha with respect to the items (variables) of which the scale is comprised. For example, criterion 1 is comprised of En13, En12, En14 and En15 and likewise all other criteria are represented by related items or variables. Hence, the reliability test was performed for each scale (criterion) and the results are shown in Tables 4.16 to 4.21 for criterion 1 to criterion 6 respectively. Criterion 7 is not required to undergo the test because only one variable is in the criterion. With the exception of the results of criterion six, all other results are over 0.7, which is the most acceptable cut-off point for reliability(Nunnally, 1975, Hinton et al., 2004, Sekaran and Bougie, 2010). Even criterion six varies its alpha value with a very little margin from 0.7; it is almost equal to 0.7. However, criterion six is at the acceptable range of reliability according to Sekaran and Bougie (2010) and Hinton et al (2004). All criteria have acceptable reliability; hence the data used to derive factors can be regarded as consistent.

Table 4.16: Reliability Statistics- Criterion 1

Reliability Statistics	
Cronbach's Alpha	N of Items
.844	4

Table 4.17: Reliability Statistics- Criterion 2

Reliability Statistics	
Cronbach's Alpha	N of Items
.709	3

Table 4.18: Reliability Statistics- Criterion 3

Reliability Statistics	
Cronbach's Alpha	N of Items
.743	5

Table 4.19: Reliability Statistics- Criterion 4

Reliability Statistics	
Cronbach's Alpha	N of Items
.776	3

Table 4.20: Reliability Statistics- Criterion 5

Reliability Statistics	
Cronbach's Alpha	N of Items
.755	3

Table 4.21: Reliability Statistics- Criterion 6

Reliability Statistics	
Cronbach's Alpha	N of Items
.694	2

4.6.2 Factor analysis results of economic key factors

Stage 1: Preliminary analysis

Economic key factors (namely Ec1 - Ec13 see Table 3.2) were the variables used in the factor analysis here. The first output of this analysis was the table of correlation matrix and its determinant value was 0.004. It is greater than the threshold value of 0.00001; therefore, it can be considered that muliticollinearity and singularity do not exist in the data. Table 4.22 shows the data of correlation matrix which is the first output for this factor analysis. Output 2 is another preliminary analysis dedicated to further checks for assessing the appropriateness of factor analysis. Output 2 obtained values of the KMO measure of sampling adequacy and Bartlett's test of sphericity, and the results are shown in Table 4.23. The values fulfil the requirements for both criteria, exceeding the value of 0.5 for the KMO measure of sampling adequacy and being less than the value of 0.05 for Bartlett's test of sphericity.

Table 4.22: Output 1: Correlation Matrix

Correlation Matrix[a]

		Ec1	Ec2	Ec3	Ec4	Ec5	Ec6	Ec7	Ec8	Ec9	Ec10	Ec11	Ec12	Ec13
Correlation	Ec1	1.000	.356	.134	.145	.210	.233	.117	.178	-.022	.157	.149	.107	.250
	Ec2	.356	1.000	.545	.626	.312	.561	.083	.132	.186	.234	.210	.194	.502
	Ec3	.134	.545	1.000	.558	.428	.501	.148	.173	.316	.365	.267	.154	.425
	Ec4	.145	.626	.558	1.000	.313	.703	.199	.188	.302	.223	.275	.146	.415
	Ec5	.210	.312	.428	.313	1.000	.371	.199	.164	.434	.692	.314	.341	.350
	Ec6	.233	.561	.501	.703	.371	1.000	.355	.267	.276	.247	.282	.180	.347
	Ec7	.117	.083	.148	.199	.199	.355	1.000	.725	.261	.229	.493	.251	.095
	Ec8	.178	.132	.173	.188	.164	.267	.725	1.000	.260	.254	.501	.264	.176
	Ec9	-.022	.186	.316	.302	.434	.276	.261	.260	1.000	.560	.377	.153	.297
	Ec10	.157	.234	.365	.223	.692	.247	.229	.254	.560	1.000	.416	.286	.326
	Ec11	.149	.210	.267	.275	.314	.282	.493	.501	.377	.416	1.000	.520	.263
	Ec12	.107	.194	.154	.146	.341	.180	.251	.264	.153	.286	.520	1.000	.179
	Ec13	.250	.502	.425	.415	.350	.347	.095	.176	.297	.326	.263	.179	1.000
Sig. (1-tailed)	Ec1		.000	.084	.068	.015	.008	.115	.033	.409	.054	.062	.136	.005
	Ec2	.000		.000	.000	.001	.000	.197	.087	.028	.008	.015	.023	.000
	Ec3	.084	.000		.000	.000	.000	.064	.038	.000	.000	.003	.056	.000
	Ec4	.068	.000	.000		.001	.000	.020	.026	.001	.010	.002	.067	.000
	Ec5	.015	.001	.000	.001		.000	.020	.046	.000	.000	.001	.000	.000
	Ec6	.008	.000	.000	.000	.000		.000	.003	.002	.005	.002	.032	.000
	Ec7	.115	.197	.064	.020	.020	.000		.000	.003	.009	.000	.005	.165
	Ec8	.033	.087	.038	.026	.046	.003	.000		.003	.004	.000	.003	.035
	Ec9	.409	.028	.000	.001	.000	.002	.003	.003		.000	.000	.058	.001
	Ec10	.054	.008	.000	.010	.000	.005	.009	.004	.000		.000	.001	.000
	Ec11	.062	.015	.003	.002	.001	.002	.000	.000	.000	.000		.000	.003
	Ec12	.136	.023	.056	.067	.000	.032	.005	.003	.058	.001	.000		.032
	Ec13	.005	.000	.000	.000	.000	.000	.165	.035	.001	.000	.003	.032	

a. Determinant = .004

Table 4.23: Output 2: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.805
Bartlett's Test of Sphericity	Approx. Chi-Square	566.283
	df	78
	Sig.	.000

Stage 2: Factor extraction

SPSS output 3 lists the Eigen values with each linear component (factor) before extraction, after extraction and after rotation. The first three columns under Initial Eigen values section show Eigen values, percentage variance of Eigen values and cumulative percentage of variance, respectively. Under the next section Extraction Sums of Squared Loadings, the results for the number of extracted factors are shown, and the first column displays the Eigen values of extracted factors. The second and third columns of the section show the results of variance individually and cumulatively. The last section, Rotation Sums of Squared Loadings, provides the details of extracted factors after rotation. The table show their Eigen values, percentage of variance of each factor and the cumulative percentage of variance. According to Table 4.24, SPSS extracted four factors for which Eigen values were greater than 1 by applying the Kaiser criterion.

Table 4.24: Output 3: Total variance explained

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.711	36.238	36.238	4.711	36.238	36.238	3.044	23.412	23.412
2	1.856	14.276	50.515	1.856	14.276	50.515	2.406	18.510	41.922
3	1.361	10.468	60.982	1.361	10.468	60.982	2.304	17.722	59.644
4	1.054	8.105	69.088	1.054	8.105	69.088	1.228	9.444	69.088
5	.868	6.675	75.763						
6	.685	5.273	81.035						
7	.529	4.072	85.107						
8	.476	3.663	88.770						
9	.372	2.862	91.632						
10	.340	2.619	94.252						
11	.275	2.116	96.368						
12	.250	1.923	98.291						
13	.222	1.709	100.000						
Extraction Method: Principal Component Analysis.									

SPSS performed a Scree test to extract factors in another way. Output 4 shows the scree plot which depicts the graph of Eigen value vs. Component number two-dimensionally (Figure 4.2). The point of inflection can be noticed after nine factors. The Kaiser criterion gives four factors and this is less than the number of factors suggested by the Scree test. Therefore, the study proceeded with the Kaiser criterion.

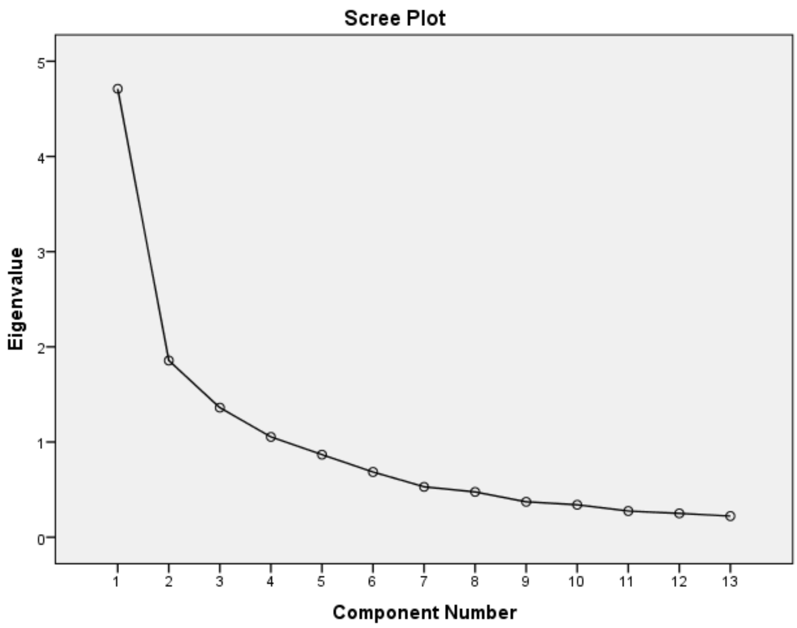


Figure 4.2: Output 4: Scree Plot

The study also checked the selection of extraction method based on two grounds for choosing the right factor extraction method suggested by Field (2009) as follows:

- If there are less than 30 variables and communalities after extraction are greater than 0.7 or if the sample size exceeds 250 and the average communality is greater than 0.6 then retain all factors with Eigen values above 1 (Kaiser's criterion)

- If none of the above apply, a Scree plot can be used when the sample size is large (around 300 or more cases)

For this purpose, Output 5 (Table 4.25) was generated and it shows the communality data initially and after extraction. According to the extracted communality data, the average communality is greater than 0.6. The sample size does not exceed 250. Nonetheless, the combined effect based on average communality value and the number of variables (less than 30) pulls the analysis towards the Kaiser criterion.

Table 4.25: Output 5: Communalities

Communalities		
	Initial	Extraction
Ec1	1.000	.728
Ec2	1.000	.753
Ec3	1.000	.621
Ec4	1.000	.782
Ec5	1.000	.718
Ec6	1.000	.719
Ec7	1.000	.811
Ec8	1.000	.772
Ec9	1.000	.678
Ec10	1.000	.788
Ec11	1.000	.649
Ec12	1.000	.480
Ec13	1.000	.483
Extraction Method: Principal Component Analysis.		

Stage 3: Factor rotation and interpretation

The un-rotated component matrix is the next important output (Output 6) before the rotation is applied. Table 4.26 is the output for the component matrix before rotation, and contains the loadings of each variable onto each factor. By default, it will display all loadings; however it shows only the loadings above 0.512 because the suppressed factor loading was chosen as 0.512. On the grounds that the sample size is more than 100, the researcher selected 0.512 as the suppressed factor loading (Stevens, 2009).

Table 4.26: Output 6: Un-rotated Component Matrix

Component Matrix[a]				
	Component			
	1	2	3	4
Ec6	.710			
Ec4	.690			
Ec3	.678			
Ec5	.674			
Ec2	.655	-.514		
Ec10	.651		-.572	
Ec11	.638			
Ec13	.605			
Ec9	.579			
Ec12				
Ec7		.597		
Ec8	.519	.581		
Ec1				.721
Extraction Method: Principal Component Analysis.				
a. 4 components extracted.				

The researcher applied orthogonal rotation for the problem because factors are independent and not correlated with one another. Output 7 is shown in Table 4.27 which represents the rotated component matrix.

Table 4.27: Rotated Component Matrix

Rotated Component Matrix _ECONOMIC[a]				
	Component			
	1	2	3	4
Ec4	.866			
Ec6	.795			
Ec2	.790			
Ec3	.714			
Ec13	.535			
Ec10		.861		
Ec5		.781		
Ec9		.683		
Ec7			.889	
Ec8			.866	
Ec11			.657	
Ec1				.824
Ec12				
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 5 iterations.				

The next step is to interpret the factors by looking at their variables. Table 4.28 gives a clear interpretation of factors looking at their associated variables and the loadings of those variables. Factor or component here is translated to criterion according to the context of the problem investigated in the present study.

Table 4.28: Factor interpretation

Component (or Criterion) number	Interpreted component	Variables (or key factors in this study)	Factor loading
1	Life cycle cost	Operation cost (Ec4)	0.866
		Routine maintenance cost (Ec6)	0.795
		Maintenance and renewal cost (Ec2)	0.790
		Replacement cost (Ec3)	0.714
		Minimizing life cycle costs (Ec13)	0.535
2	Land value	Community land value (Ec10)	0.861
		Residual value including land value (Ec5)	0.781
		Revenue generation for the council (Ec9)	0.683
3	Local economy	small business advancement in the local government area (Ec11)	0.889
		Use of local materials and local suppliers (Ec8)	0.866
		Local employment opportunity (Ec7)	0.657
4	Additional capital investment	Additional capital investment cost (Ec1)	0.824

Stage 4: Reliability analysis of derived factors

The reliability of each factor is tested by calculating the Cronbach's alpha with respect to the items (variables) that the scale is comprised of. For example, criterion 1 is comprised of Ec4, Ec6, Ec2, Ec3 and Ec13 and likewise all other criteria are represented by related items or variables. Hence, the reliability test was performed for each scale (criterion) and the results are shown in Tables 4.29 to 4.31 for criterion 1 to criterion 3 respectively. Criterion 4 is not required to undergo the test because only one variable is in the criterion. According to the tables, the Cronbach's alpha value at each situation was well over 0.7 Hence, all the results show the reliability of the data related to each criterion (Nunnally, 1975, Hinton et al., 2004, Sekaran and Bougie, 2010).

Table 4.29: Reliability Statistics- Criterion 1

Reliability Statistics	
Cronbach's Alpha	N of Items
.838	5

Table 4.30: Reliability Statistics- Criterion 2

Reliability Statistics	
Cronbach's Alpha	N of Items
.793	3

Table 4.31: Reliability Statistics- Criterion 3

Reliability Statistics	
Cronbach's Alpha	N of Items
.801	3

4.6.3 Factor analysis results of social key factors

Stage 1: Preliminary analysis

Social key factors (namely Sc1 - Sc17; see Table 3.3) were the variables used in the factor analysis. The first output of this analysis was the table of correlation matrix and its determinant value was 0.0000963. It is greater than the threshold value of 0.00001. Therefore, it can be considered that mulitcollinearity and singularity do not exist in the data. Table 4.32 shows the data for the correlation matrix which comes under the heading of output 1 for this factor analysis. Output 2 of this analysis obtained values of KMO measure of sampling adequacy and Bartlett's test of sphericity, and the values are shown in Table 4.33. The values supported the continuance of further analysis by fulfilling the requirements of both criteria; exceeding the value of 0.5 for the KMO measure of sampling adequacy and being less than the value of 0.05 for Bartlett's test of sphericity.

Table 4.32: Output 1: Correlation Matrix

Correlation Matrix[a]

		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Sc11	Sc12	Sc13	Sc14	Sc15	Sc16	Sc17
Correlation	Sc1	1.000	.613	.126	.188	.379	.451	.298	.329	.351	.323	.193	.026	.018	.185	.005	.010	.234
	Sc2	.613	1.000	.450	.502	.432	.511	.435	.074	.269	.385	.270	.196	.322	.334	.296	.261	.405
	Sc3	.126	.450	1.000	.553	.554	.589	.563	.048	.337	.311	.383	.382	.395	.320	.277	.381	.296
	Sc4	.188	.502	.553	1.000	.542	.411	.412	.076	.207	.370	.321	.327	.477	.376	.274	.372	.340
	Sc5	.379	.432	.554	.542	1.000	.682	.613	.262	.304	.392	.425	.459	.454	.461	.383	.437	.438
	Sc6	.451	.511	.589	.411	.682	1.000	.735	.099	.447	.416	.412	.250	.180	.253	.226	.275	.458
	Sc7	.298	.435	.563	.412	.613	.735	1.000	.040	.251	.368	.375	.400	.263	.420	.346	.426	.493
	Sc8	.329	.074	.048	.076	.262	.099	.040	1.000	.213	.115	.240	-.006	.136	.163	.029	.105	.306
	Sc9	.351	.269	.337	.207	.304	.447	.251	.213	1.000	.364	.457	.186	.177	.192	.110	.092	.142
	Sc10	.323	.385	.311	.370	.392	.416	.368	.115	.364	1.000	.447	.191	.273	.234	.225	.285	.236
	Sc11	.193	.270	.383	.321	.425	.412	.375	.240	.457	.447	1.000	.308	.282	.281	.163	.240	.311
	Sc12	.026	.196	.382	.327	.459	.250	.400	-.006	.186	.191	.308	1.000	.618	.623	.495	.419	.275
	Sc13	.018	.322	.395	.477	.454	.180	.263	.136	.177	.273	.282	.618	1.000	.728	.538	.434	.271
	Sc14	.185	.334	.320	.376	.461	.253	.420	.163	.192	.234	.281	.623	.728	1.000	.584	.495	.397
	Sc15	.005	.296	.277	.274	.383	.226	.346	.029	.110	.225	.163	.495	.538	.584	1.000	.658	.343
	Sc16	.010	.261	.381	.372	.437	.275	.426	.105	.092	.285	.240	.419	.434	.495	.658	1.000	.382
	Sc17	.234	.405	.296	.340	.438	.458	.493	.306	.142	.236	.311	.275	.271	.397	.343	.382	1.000

Sig. (1-tailed)	Sc1		.000	.098	.026	.000	.000	.001	.000	.000	.000	.023	.396	.425	.029	.480	.461	.008
	Sc2	.000		.000	.000	.000	.000	.000	.224	.003	.000	.002	.021	.000	.000	.001	.003	.000
	Sc3	.098	.000		.000	.000	.000	.000	.313	.000	.001	.000	.000	.000	.000	.002	.000	.001
	Sc4	.026	.000	.000		.000	.000	.000	.218	.016	.000	.000	.000	.000	.000	.002	.000	.000
	Sc5	.000	.000	.000	.000		.000	.000	.003	.001	.000	.000	.000	.000	.000	.000	.000	.000
	Sc6	.000	.000	.000	.000	.000		.000	.156	.000	.000	.000	.005	.032	.004	.010	.002	.000
	Sc7	.001	.000	.000	.000	.000	.000		.342	.005	.000	.000	.000	.003	.000	.000	.000	.000
	Sc8	.000	.224	.313	.218	.003	.156	.342		.014	.120	.006	.474	.081	.047	.383	.141	.001
	Sc9	.000	.003	.000	.016	.001	.000	.005	.014		.000	.000	.028	.034	.024	.130	.172	.072
	Sc10	.000	.000	.001	.000	.000	.000	.000	.120	.000		.000	.025	.002	.008	.010	.001	.007
	Sc11	.023	.002	.000	.000	.000	.000	.000	.006	.000	.000		.001	.002	.002	.047	.006	.001
	Sc12	.396	.021	.000	.000	.000	.005	.000	.474	.028	.025	.001		.000	.000	.000	.000	.002
	Sc13	.425	.000	.000	.000	.000	.032	.003	.081	.034	.002	.002	.000		.000	.000	.000	.002
	Sc14	.029	.000	.000	.000	.000	.004	.000	.047	.024	.008	.002	.000	.000		.000	.000	.000
	Sc15	.480	.001	.002	.002	.000	.010	.000	.383	.130	.010	.047	.000	.000	.000		.000	.000
	Sc16	.461	.003	.000	.000	.000	.002	.000	.141	.172	.001	.006	.000	.000	.000	.000		.000
	Sc17	.008	.000	.001	.000	.000	.000	.000	.001	.072	.007	.001	.002	.002	.000	.000	.000	

a. Determinant = 9.63E-005

Table 4.33: Output 2: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.828
Bartlett's Test of Sphericity	Approx. Chi-Square	920.143
	df	136
	Sig.	.000

Stage 2: Factor extraction

SPSS output 3 lists the Eigen values with each linear component (factor) before extraction, after extraction and after rotation. The first three columns under Initial Eigen values show Eigen values, percentage variance of Eigen values and cumulative percentage of variance respectively. Under the next section Extraction Sums of Squared Loadings, the results of number of extracted factors are shown, and the first column displays the Eigen values of extracted factors. The second and third columns of the section show the results of variance individually and cumulatively. The last section, Rotation Sums of Squared Loadings, provides the details of extracted factors after rotation. The details show their Eigen values, percentage of variance of each factor and the cumulative percentage of variance. According to Table 4.34, SPSS extracted four factors for which Eigen values were greater than 1 by applying the Kaiser criterion.

Table 4.34: Output 3: Total variance explained

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.529	38.408	38.408	6.529	38.408	38.408	3.709	21.815	21.815
2	2.129	12.526	50.934	2.129	12.526	50.934	3.698	21.755	43.570
3	1.246	7.327	58.261	1.246	7.327	58.261	2.152	12.656	56.226
4	1.106	6.504	64.765	1.106	6.504	64.765	1.452	8.538	64.765
5	.952	5.600	70.365						
6	.805	4.734	75.100						
7	.779	4.580	79.680						
8	.616	3.624	83.304						
9	.563	3.314	86.618						
10	.438	2.574	89.192						
11	.382	2.249	91.441						
12	.345	2.028	93.470						
13	.340	1.998	95.468						
14	.260	1.527	96.995						
15	.206	1.209	98.204						
16	.161	.949	99.153						
17	.144	.847	100.000						
Extraction Method: Principal Component Analysis.									

SPSS performed a Scree test to extract factors in another way. Output 4 shows the scree plot which depicts the graph of Eigen value vs. Component number two-dimensionally (Figure 4.3). The point of inflection can be noticed after four factors, which is the same number of factors suggested by the Kaiser criterion. Hence, the selection of the right extraction method based on two grounds as suggested by Field (2009) was not required to be undertaken.

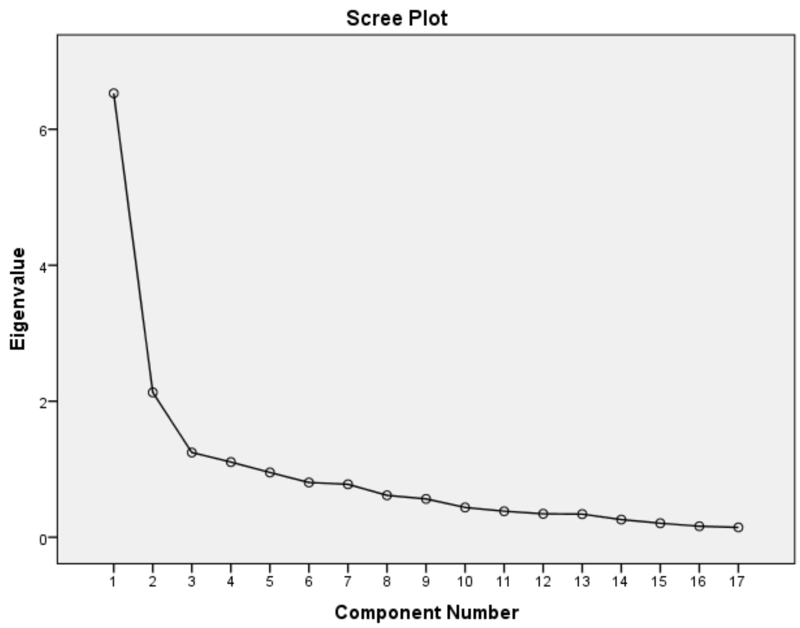


Figure 4.3: Output 4: Scree Plot

Stage 3: Factor rotation and interpretation

The un-rotated component matrix is the next important output (Output 6) before rotation is applied. Table 4.35 is the output for the component matrix before rotation, and contains the loadings of each variable onto each factor. By default, it will display all loadings. However, it shows only the loadings above 0.512 because the suppressed factor loading was chosen as 0.512. On the grounds that sample size is more than 100, the study selected 0.512 as the suppressed factor loading (Stevens, 2009).

Table 4.35: Output 6: Un-rotated Component Matrix

Component Matrix[a]				
	Component			
	1	2	3	4
Sc5	.806			
Sc7	.745			
Sc6	.728			
Sc3	.697			
Sc14	.687			
Sc4	.669			
Sc2	.651			
Sc13	.643			
Sc16	.618			
Sc12	.612			
Sc17	.606			
Sc15	.586	-.534		
Sc11	.574			
Sc10	.560			
Sc1		.613		
Sc8			.784	
Sc9				
Extraction Method: Principal Component Analysis.				
a. 4 components extracted.				

The researcher applied orthogonal rotation for the problem because factors are independent and not correlated with one another. Output 7 is shown in Table 4.36 which represents the rotated component matrix.

Table 4.36: Rotated Component Matrix

Rotated Component Matrix _SOCIAL[a]				
	Component			
	1	2	3	4
Sc13	.812			
Sc14	.807			
Sc15	.782			
Sc12	.739			
Sc16	.698			
Sc6		.813		
Sc7		.756		
Sc2		.732		
Sc5		.609		
Sc3		.588		
Sc4		.527		
Sc17		.513		
Sc9			.773	
Sc11			.748	
Sc10			.540	
Sc8				.821
Sc1		[redacted]		.607
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 7 iterations.				

The next step is to interpret the factors by considering their variables. Table 4.37 gives a clear interpretation of factors looking at their associated variables and loadings of those variables. Factor or component here is translated to criterion according to the context of the problem investigated in the present study.

Table 4.37: Factor interpretation

Component (or Criterion) number	Interpreted component	Variables (or key factors in this study)	Factor loading
1	Local community engagement	Number of community members that will benefit (Sc16)	0.812
		Local community support (Sc14)	0.807
		Level of community demand (Sc15)	0.782
		Local community involved (Sc12)	0.739
		Local community expectation (Sc13)	0.698
2	Community benefits and equity	Feeling of security (Sc6)	0.813
		Impact on healthy life style (Sc7)	0.756
		Equity of users (Sc2)	0.732
		Community's health/well-being (The hygienic condition) (Sc5)	0.609
		Provision of recreational and essential facilities (Sc3)	0.588
		Accessibility (Sc4)	0.527
		Proximity via public transport, cycling, walking (Sc17)	0.513
3	Neighbourhood character	Image of the council (Sc10)	0.773
		Aesthetics (Sc11)	0.748
		Heritage value of the building (Sc9)	0.540
4	Employee well-being	Usage of hazardous goods and materials (Sc8)	0.821
		Equity of employees (Sc1)	0.607

Stage 4: Reliability analysis of derived factors

The reliability of each factor is tested by calculating Cronbach's alpha with respect to the items (variables) that the scale is comprised of. For example, criterion 1 is comprised of Sc16, Sc14, Sc15, Sc12 and Sc13 and likewise all other criteria are represented by related items or variables. Hence, reliability testing was performed for each scale (criterion) and the results are shown in Tables 4.38 to 4.41 for criterion 1 to criterion 4 respectively. Criterion 1 and criterion 2 clearly show great internal consistency, as both alpha values exceed 0.85 (Nunnally, 1975, Hinton et al., 2004, Sekaran and Bougie, 2010). However, the alpha value of criterion 3 is less than 0.7 but over the value of 0.6. Hence, criterion 3 is of acceptable internal consistency according to Sekaran and Bougie (2010). In contrast, criterion 4 has an alpha value of 0.482, which is far below the figure required for consistency of data. According to Kline (1999), this kind of situation is common for social science data. However, the given criterion is comprised of only two items, so its reduced reliability is not dramatically affected by the number of items (Field, 2009).

Table 4.38: Reliability Statistics- Criterion 1

Reliability Statistics	
Cronbach's Alpha	N of Items
.862	5

Table 4.39: Reliability Statistics- Criterion 2

Reliability Statistics	
Cronbach's Alpha	N of Items
.867	7

Table 4.40: Reliability Statistics- Criterion 3

Reliability Statistics	
Cronbach's Alpha	N of Items
.673	3

Table 4.41: Reliability Statistics- Criterion 4

Reliability Statistics	
Cronbach's Alpha	N of Items
.482	2

4.6.4 Factor analysis results of functional key factors

Stage 1: Preliminary analysis

Functional key factors (namely Fn1 - Fn14; see Table 3.4) were the variables used in the factor analysis here. The first output of this analysis was the table of correlation matrix which is given in Table 4.42. Its determinant value was found to be 0.000, but a rigorous scan of its significant values and correlation co-efficient values could not provide any suggestion of omission of any variable causing multicollinearity or singularity. However, Haitovsky (1969) suggests that there is no severe multicollinearity in situations where the determinant of the correlation matrix becomes zero. Therefore, factor analysis was continued using the same number of variables and output 2 (Table 4.43) was obtained, which shows the values of the KMO measure of sampling adequacy and Bartlett’s test of sphericity. These values prove the credibility of the continuation of factor analysis because both values met the requirement.

Table 4.42: Output 1: Correlation Matrix

Correlation Matrix[a]

		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
Correlation	F1	1.000	.669	.584	.465	.328	.455	.340	.350	.327	.367	.292	.286	.211	.257
	F2	.669	1.000	.688	.447	.346	.603	.335	.374	.403	.364	.277	.384	.337	.358
	F3	.584	.688	1.000	.555	.448	.612	.388	.331	.296	.325	.321	.350	.380	.342
	F4	.465	.447	.555	1.000	.609	.435	.344	.519	.400	.331	.234	.121	.118	.207
	F5	.328	.346	.448	.609	1.000	.408	.464	.399	.515	.485	.359	.097	.088	.102
	F6	.455	.603	.612	.435	.408	1.000	.477	.423	.374	.459	.333	.278	.239	.216
	F7	.340	.335	.388	.344	.464	.477	1.000	.348	.567	.476	.349	.362	.341	.350
	F8	.350	.374	.331	.519	.399	.423	.348	1.000	.561	.398	.321	.423	.363	.409
	F9	.327	.403	.296	.400	.515	.374	.567	.561	1.000	.480	.527	.389	.401	.342
	F10	.367	.364	.325	.331	.485	.459	.476	.398	.480	1.000	.567	.146	.197	.164
	F11	.292	.277	.321	.234	.359	.333	.349	.321	.527	.567	1.000	.202	.294	.195
	F12	.286	.384	.350	.121	.097	.278	.362	.423	.389	.146	.202	1.000	.851	.731
	F13	.211	.337	.380	.118	.088	.239	.341	.363	.401	.197	.294	.851	1.000	.759
	F14	.257	.358	.342	.207	.102	.216	.350	.409	.342	.164	.195	.731	.759	1.000
Sig. (1-tailed)	F1		.000	.000	.000	.000	.000	.000	.000	.000	.000	.001	.001	.015	.004
	F2	.000		.000	.000	.000	.000	.000	.000	.000	.000	.002	.000	.000	.000
	F3	.000	.000		.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000
	F4	.000	.000	.000		.000	.000	.000	.000	.000	.000	.008	.108	.113	.017
	F5	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000	.162	.184	.149
	F6	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.002	.007	.013
	F7	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000
	F8	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000
	F9	.000	.000	.001	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000
	F10	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000	.068	.021	.046
	F11	.001	.002	.000	.008	.000	.000	.000	.000	.000	.000		.019	.001	.022
	F12	.001	.000	.000	.108	.162	.002	.000	.000	.000	.068	.019		.000	.000
	F13	.015	.000	.000	.113	.184	.007	.000	.000	.000	.021	.001	.000		.000
	F14	.004	.000	.000	.017	.149	.013	.000	.000	.000	.046	.022	.000	.000	

a. Determinant = .000

Table 4.43: Output 2: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.834
Bartlett's Test of Sphericity	Approx. Chi-Square	842.437
	df	91
	Sig.	.000

<u>Stage 2: Factor extraction</u>

SPSS output 3 lists the Eigen values with each linear component (factor) before extraction, after extraction and after rotation. The first three columns under Initial Eigen values show Eigen values, percentage variance of Eigen values and cumulative percentage of variance, respectively. Under the next section Extraction Sums of Squared Loadings, the results of the number of extracted factors are shown, and the first column displays the Eigen values of extracted factors. The second and third columns of the section show the results of variance individually and cumulatively. The last section, Rotation Sums of Squared Loadings, provides the details of extracted factors after rotation. The details show their Eigen values, percentage of variance of each factor and the cumulative percentage of variance. According to Table 4.44, SPSS extracted three factors for which Eigen values were greater than 1 by applying the Kaiser criterion.

Table 4.44: Output 3: Total variance explained

Total Variance Explained									
	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.999	42.850	42.850	5.999	42.850	42.850	3.296	23.540	23.540
2	2.042	14.584	57.433	2.042	14.584	57.433	3.214	22.956	46.496
3	1.331	9.510	66.943	1.331	9.510	66.943	2.863	20.447	66.943
4	.899	6.425	73.368						
5	.686	4.897	78.265						
6	.577	4.120	82.385						
7	.536	3.829	86.214						
8	.452	3.230	89.444						
9	.379	2.710	92.154						
10	.305	2.182	94.336						
11	.253	1.805	96.141						
12	.237	1.696	97.837						
13	.189	1.349	99.187						
14	.114	.813	100.000						
Extraction Method: Principal Component Analysis.									

SPSS performed the scree test to extract factors in another way. Output 4 shows the scree plot which depicts the graph of Eigen value vs. Component number two-dimensionally (Figure 4.4). The point of inflection can be noticed after six factors. The Kaiser criterion provides three factors and this is less than the number of factors suggested by the scree test. Therefore, the study proceeded with the Kaiser criterion.

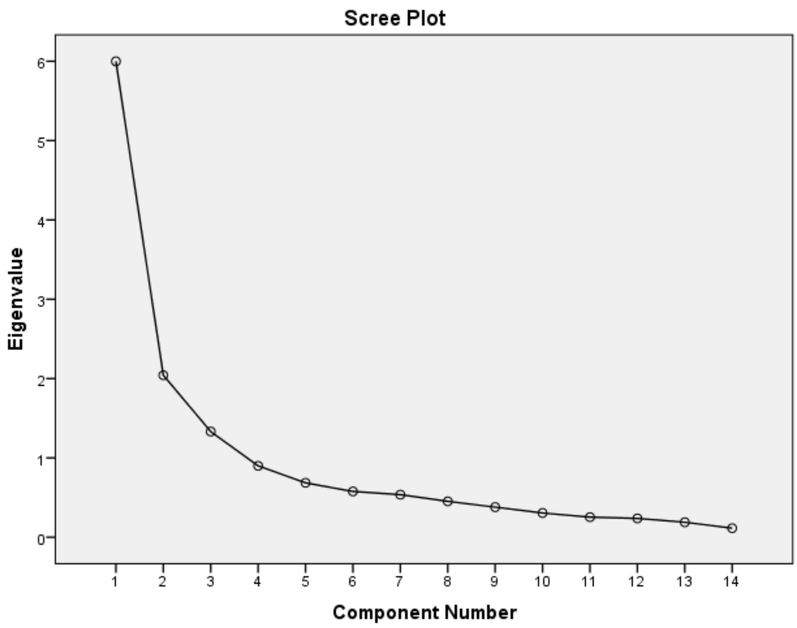


Figure 4.4: Output 4: Scree Plot

The study also checked the selection of extraction method based on the two grounds for choosing the right factor extraction method suggested by Field (2009) as follows:

- If there are less than 30 variables and communalities after extraction are greater than 0.7 or if the sample size exceeds 250 and the average communality is greater than 0.6 then retain all factors with Eigen values above 1 (Kaiser's criterion)

- If none of the above apply, a Scree plot can be used when the sample size is large (around 300 or more cases)

For this purpose, Output 5 (Table 4.45) was generated and it shows the communality data initially and after extraction. According to the extracted communality data, average communality is greater than 0.6. The sample size does not exceed 250. Nonetheless, the combined effect based on average communality value and the number of variables (less than 30) pulls the analysis towards the Kaiser criterion.

Table 4.45: Output 5: Communalities

Communalities		
	Initial	Extraction
F1	1.000	.637
F2	1.000	.752
F3	1.000	.760
F4	1.000	.583
F5	1.000	.629
F6	1.000	.590
F7	1.000	.525
F8	1.000	.489
F9	1.000	.712
F10	1.000	.629
F11	1.000	.544
F12	1.000	.869
F13	1.000	.875
F14	1.000	.778
Extraction Method: Principal Component Analysis.		

<u>Stage 3: Factor rotation and interpretation</u>

The un-rotated component matrix is the next important output (Output 6) before the rotation is applied. Table 4.46 is the output for the component matrix before rotation, and contains the loadings of each variable onto each factor. By default, it will display all loadings. However, it shows only the loadings above 0.512 because the suppressed factor loading was chosen as 0.512. On the grounds that sample size is more than 100, the study selected 0.512 as the suppressed factor loading (Stevens, 2009).

Table 4.46: Output 6: Un-rotated Component Matrix

Component Matrix[a]			
	Component		
	1	2	3
F3	.735		
F2	.733		
F9	.720		
F6	.703		
F8	.680		
F7	.673		
F1	.657		
F4	.640		
F10	.628		
F5	.622		
F11	.567		
F13	.594	.720	
F12	.601	.712	
F14	.579	.665	
Extraction Method: Principal Component Analysis.			
a. 3 components extracted.			

The study applied orthogonal rotation for the problem because factors are independent and not correlated with one another. Output 7 is shown in Table 4.47 which presents the rotated component matrix.

Table 4.47: Rotated Component Matrix

Rotated Component Matrix FUNCTIONAL[a]			
	Component		
	1	2	3
F3	.824		
F2	.811		
F1	.767		
F6	.669		
F4	.652		
F9		.770	
F10		.756	
F11		.719	
F5		.663	
F7		.623	
F8		.525	
F13			.912
F12			.907
F14			.856
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.			
a. Rotation converged in 5 iterations.			

The next step is to interpret the factors by looking at their variables. Table 4.48 gives a clear interpretation of factors considering their associated variables and the loadings of those variables. Factor or component here is translated to criterion according to the context of the problem investigated in the present study.

Table 4.48: Factor interpretation

Component (or Criterion) number	Interpreted component	Variables (or key factors in this study)	Factor loading
1	Impact of failure and response	Availability of alternative resources (Fn4)	0.824
		Severity of failure (Fn2)	0.811
		Number of users affected due to failure (Fn1)	0.767
		Likelihood of failure (Fn6)	0.669
		Length of interruption to service (Fn3)	0.652
2	Minimum level of service	Accountability to users (Fn9)	0.770
		The ability to meet short term demands (Fn10)	0.756
		The ability to meet long term demands (Fn11)	0.719
		Adaptability of users to a proposed change (Fn5)	0.663
		Minimum acceptable level of service (Fn8)	0.623
		Facilities and services management (Fn7)	0.525
		Accountability to users (Fn9)	0.770
3	Compliance to building standards and regulations	Compliance to disability (Fn14)	0.912
		Compliance to the Building Code (Fn12)	0.907
		Compliance to the OHS standards (Fn13)	0.856

Stage 4: Reliability analysis of derived factors

The reliability of each factor is tested by calculating Cronbach's alpha with respect to the items (variables) that the scale is comprised of. For example, criterion 1 is comprised of Fn4, Fn2, Fn1, Fn6 and Fn3 and likewise all other criteria are represented by related items or variables. Hence, the reliability test was performed for each scale (criterion) and the results are shown in Tables 4.49 to 4.51 for criterion 1 to criterion 3, respectively. According to the tables, Cronbach's alpha for each situation is well over 0.7. Hence, all the results show the reliability of the data related to each criterion (Nunnally, 1975, Hinton et al., 2004, Sekaran and Bougie, 2010).

Table 4.49: Reliability Statistics- Criterion 1

Reliability Statistics	
Cronbach's Alpha	N of Items
.858	5

Table 4.50: Reliability Statistics- Criterion 2

Reliability Statistics	
Cronbach's Alpha	N of Items
.833	6

Table 4.51: Reliability Statistics- Criterion 3

Reliability Statistics	
Cronbach's Alpha	N of Items
.913	3

4.7 Summary of findings of Questionnaire 1

The main intention of Questionnaire 1 was to refine the tailor-made factors sourced from the literature review and expert opinions in relation to the sustainable management of community buildings. However, its responses lead to another investigation, to validate the listed factors based on the opinions of the majority of local councils in Australia. Average index was the main tool utilized in the validation process and all the results suggest that all the factors have been validated to a large extent. All the validated factors were then subjected to factor analysis which was intended to refine the factors. A detailed analysis was conducted under four main stages: preliminary analysis, factor extraction, factor rotation and interpretation, and reliability analysis of derived factors. Based on the results, the research pinpointed 18 key criteria to address the sustainable management of community buildings. Of these 18 criteria, 7 relate to the environmental aspect while 4 relate to the economic and social aspects, and 3 to the functional aspect.

5 DETERMINATION OF WEIGHTINGS OF INFLUENCING FACTORS

5.1 Introduction

This chapter first presents the background to the conduct of the second industry-wide questionnaire, and then describes the purpose of the questionnaire, data collection, questionnaire development and data reliability. The intended respondents to this questionnaire were practitioners at local councils in Australia who engage in the management of community buildings on a daily basis. This questionnaire was also created using Survey Monkey web-based software and circulated via the web. The latter part of the chapter is dedicated to the data analysis process.

5.2 Purpose of the Industry-wide Questionnaire 2

The main purpose of the questionnaire was to capture the data on the pair-wise comparison of the opinions of local council professionals on the derived criteria and their related aspects. The model is explained in Chapter 6 and it required obtaining the weighting of each criteria and aspect for the final outcome. Weighting is one index required to calculate the aggregated result of the combined effect out of several variables. In other words, it denotes the extent of significance of each variable to the combined effect. Coupled with the nature of the problem, weightings of environmental criteria have an effect on the total environmental impact. Likewise, weightings of the economic, social and functional criteria affect the overall impact of the economic, social and functional aspect, respectively. Finally, the weighting of each aspect has a large impact on the corporate (total) sustainability impact. However, weighting values are fixed because the significance is considered in terms of the whole context of building management. Hence, they do not vary depending on the given building component.

5.3 Data collection

Multi-criteria decision-making refers to selecting or ranking alternative(s) from available alternatives with respect to multiple but usually conflicting criteria. In practical situations, subjectivity and imprecision are always present in the multi-criteria decision-making process (Chen et al., 1992). However, fuzzy AHP has the ability to minimise subjectivity and imprecision compared with general AHP. In one council context, pair-wise comparison opinions can be collected according to the opinions of one person or group in the council. Hence, if the model is developed for a particular council, fuzzy AHP is the best approach. However, the objective of the proposed model is to be applicable widely. Therefore, opinions were sought from and decisions made for, local councils in Australia.

Moving from a single decision-maker's setting to a group decision-makers' setting increases the complexity in the decision-making process. The pilot survey among the research group suggested the practical impossibility of obtaining opinions via a questionnaire using a fuzzy AHP preference table rather than the general AHP preference table. Therefore, the questionnaire was designed according to Satty's general preference table. Also, most applications in the research literature involve a small number of experts (mostly less than ten) in giving their opinions. However, the higher the number of experts involved, the greater the appropriateness of the solution. Hence, the researcher tried to capture as many responses as possible from the questionnaire. Similarly in Questionnaire 1, the target group of respondents was local council professionals in Australia who are engaged in building management practice day-to-day. The responses obtained fluctuated between a minimum of 46 responses and a maximum of 48 responses, which was an excellent outcome for problems of such a nature.

5.4 Questionnaire development

A similar pilot study to that applied for Questionnaire 1 was carried out for Questionnaire 2. The initial draft was tested by the research team, including two supervisors, two research fellows and one PhD student. The next phase of the pilot study involved practitioners from the partner councils in further testing the draft modified by the research group. Based on their feedback, the final questionnaire was formulated using the Survey Monkey web-based software, and the link was circulated to local councils via email. The questionnaire consisted of two sections, as in Questionnaire 1, in which Section A captured demographic data while Section B captured pair-wise comparison data. Example questions for both sections are shown in the following sub-sections and the total questionnaire is provided in Appendix C.

Section A

1. Respondent Current Position:

2. How long have you been working in the current position?

3. Number of buildings under management of the council:

4. Please insert the state in Australia where your organisation is located:

5. Total years of work experience in building management:

Section B

Please give your rating on the relative importance of the first aspect compared to the second aspect (Please keep your responses consistent with your previous ranking results)

	Absolute Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate Least Importance	Strong Least Importance	Very Strong Least Importance	Very Strong Least Importance
Environmental aspect Vs Economic aspect									
Environmental aspect Vs Social aspect									
Environmental aspect Vs Functional aspect									
Economic aspect Vs Social aspect									
Economic aspect Vs Functional aspect									
Social aspect Vs Functional aspect									

5.5 Data reliability

Obtaining data for Questionnaire 2 was complex compared to Questionnaire 1. The nature of giving responses was completely different because the respondent needed to be aware of each item of the set prior to giving the pair-wise opinion. In this case, consistency of data is essential in terms of the reliability of the result. Fortunately, Saaty's AHP has an inbuilt consistency check of data, which is reflected by the consistency ratio (a detailed explanation of the consistency ratio was given in Section 2.7.1).

5.6 Process of the calculation of weightings

In accordance with Section 2.7.1, the calculation process followed the following order of outputs:

Output 1: Matrix of comparison data

Output 2: Normalization of the matrix and weighting calculation

Output 3: Calculation of λ_{max}

Output 4: Calculation of consistency ratio (CR)

5.6.1 Weighting calculation of sustainability aspects

The total number of responses received was 48 for comparing the aspects against the significance to corporate (total) sustainability impact. Based on the average values, a matrix of comparison data was developed and it is shown in Table 5.1 (Output 1). Note that the symbols En, Ec, Sc and Fn represent the environmental, economic, social and functional aspects, respectively. The normalized matrix based on the output 1 data is shown in Table 5.2 with the calculated values of weighting of each aspect. The next step after obtaining the weighting values was to check the reliability of the values by carrying out the consistency check on the input pair-wise data. The main task of the reliability-check process was to calculate the consistency ratio, which first requires λ_{max} to be calculated. Table 5.3 shows how λ_{max} is calculated according to the data of the normalized matrix and the derived weighting values (see Equations 2.9 and 2.10 in Chapter 2).

The consistency ratio is depicted by the consistency index (CI) and random consistency value (R) (see Equation 2.7 in Chapter 2). Since the size of the matrix (n) is known and λ_{max} is already calculated, CI can be calculated by Equation 2.8 in Chapter 2. R varies according to the size of matrix, however no calculation is required because those values are already known and are shown in Table 2.24. The R value related to the current problem is 0.90 due to the size of matrix being equal to 4. Pedrycz and Gomide (2007) reported that consistency of results can be assured if the analysis can obtain a CI value less than 0.1. Since their recommendation was mainly relied on fuzzy AHP data, making the decision based on CR value (CR is less than 0.1) is beyond doubt for any situation. Table 5.4 is the numerical illustration of the calculation of CI and CR values. Both values are less than 0.1, which confirms the consistency of pair-wise data used in the current situation on either criterion, CI or CR.

Table 5.1: Output 1: Matrix of comparison data

	En	Ec	Sc	Fn
En	1	1.9651	2.0002	1.5264
Ec	0.5089	1	2.1421	1.5581
Sc	0.4999	0.4668	1	1.4668
Fn	0.6551	0.6418	0.6818	1
Σ	2.6639	4.0737	5.8242	5.5513

Table 5.2: Output 2: Normalized matrix and calculated weighting values

	En	Ec	Sc	Fn	Sum	Weighting
En	0.3753	0.4824	0.3435	0.2750	1.4762	0.3691
Ec	0.1910	0.2455	0.3678	0.2807	1.0850	0.2712
Sc	0.1876	0.1146	0.1717	0.2642	0.7382	0.1845
Fn	0.2459	0.1576	0.1171	0.1801	0.7006	0.1752
Sum	1	1	1	1	4	1

Table 5.3: Calculation of λmax

	En	Ec	Sc	Fn	Weighting	R	Overall λmax
En	0.3753	0.4824	0.3435	0.2750	0.3691	4.1691	4.1239
Ec	0.1910	0.2455	0.3678	0.2807	0.2712	4.1560	
Sc	0.1876	0.1146	0.1717	0.2642	0.1845	4.0781	
Fn	0.2459	0.1576	0.1171	0.1801	0.1752	4.0923	

Table 5.4: Calculation of CI and CR

n	λmax	CI	R	CR
4	4.1239	0.0413	0.90	0.0459

5.6.2 Weighting calculation of environmental criteria

The total number of responses received was 46 comparing the environmental criteria against the significance to the total impact caused by the environmental aspect. Based on their average values, a matrix of comparison data was developed and it is shown in Table 5.5 (Output 1). Note that the symbols En1 to En7 represent seven environmental criteria. The normalized matrix based on the Output 1 data is shown in Table 5.6 with the calculated values of weighting of each criterion. Table 5.7 shows how λ_{max} is calculated according to the data of the normalized matrix and the derived weighting value matrix. R related to the current problem is 1.32 due to the size of matrix being equal to 7. Table 5.8 gives the numerical illustration of the calculation of CI and CR values. Both values are less than 0.1, confirming the consistency of pair-wise data used in the current situation on either criterion, CI or CR.

Table 5.5: Output 1: Matrix of comparison data

	E1	E2	E3	E4	E5	E6	E7
E1	1	1.7031	1.2450	2.3391	2.4464	2.3367	2.5002
E2	0.5872	1	1.4074	2.4306	2.9640	2.4712	2.7424
E3	0.8058	0.7105	1	2.7536	3.3884	2.8783	2.9826
E4	0.4275	0.4114	0.3631	1	2.0944	2.0108	2.1538
E5	0.4088	0.3374	0.2951	0.4775	1	1.5367	1.5917
E6	0.4280	0.4047	0.3474	0.4973	0.6508	1	1.7797
E7	0.4000	0.3646	0.3352	0.4643	0.6282	0.5619	1
Sum	4.0573	4.9317	4.9892	9.9624	13.1722	12.7956	14.7504

Table 5.6: Output 2: Normalized matrix and calculated weighting values

	E1	E2	E3	E4	E5	E6	E7	Sum	Weightings
E1	0.246	0.345	0.249	0.235	0.186	0.183	0.170	1.613	0.2304
E2	0.145	0.203	0.282	0.244	0.225	0.193	0.186	1.478	0.2111
E3	0.199	0.144	0.200	0.276	0.257	0.224	0.202	1.504	0.2148
E4	0.105	0.083	0.072	0.100	0.159	0.157	0.146	0.824	0.1177
E5	0.101	0.068	0.059	0.048	0.076	0.120	0.108	0.580	0.0829
E6	0.105	0.082	0.070	0.050	0.049	0.078	0.121	0.555	0.0793
E7	0.099	0.074	0.067	0.047	0.048	0.044	0.068	0.446	0.0637
Sum	1	1	1	1	1	1	1	7	1

Table 5.7: Calculation of λmax

	E1	E2	E3	E4	E5	E6	E7	W	R	λmax
E1	1	1.7031	1.2450	2.3391	2.4464	2.3367	2.5002	0.2304	7.457	7.482
E2	0.5872	1	1.4074	2.4306	2.9640	2.4712	2.7424	0.2111	7.552	
E3	0.8058	0.7105	1	2.7536	3.3884	2.8783	2.9826	0.2148	7.543	
E4	0.4275	0.4114	0.3631	1	2.0944	2.0108	2.1538	0.1177	7.518	
E5	0.4088	0.3374	0.2951	0.4775	1	1.5367	1.5917	0.0829	7.433	
E6	0.4280	0.4047	0.3474	0.4973	0.6508	1	1.7797	0.0793	7.459	
E7	0.4000	0.3646	0.3352	0.4643	0.6282	0.5619	1	0.0637	7.410	

Table 5.8: Calculation of CI and CR

n	λmax	CI	R	CR
7	7.482	0.08	1.32	0.06

5.6.3 Weighting calculation of economic criteria

The total number of responses received was 46 comparing the economic criteria against the significance to the total impact caused by the economic aspect. Based on their average values, a matrix of comparison data was developed and it is shown in Table 5.9 (Output 1). Note that the symbols Ec1, Ec2, Ec3 and Ec4 represent four economic criteria. The normalized matrix based on the Output 1 data is shown in Table 5.10 with the calculated values of weighting of each criterion. Table 5.11 shows how λ_{max} is calculated according to the data of the normalized matrix and the derived weighting values. The R value related to the current problem is 0.90 due to the size of matrix which is equal to 4. Table 5.12 provides the numerical illustration of the calculation of the CI and CR values. Both values are less than 0.1, confirming the consistency of pair-wise data used in the current situation on either criterion, CI or CR.

Table 5.9: Output 1: Matrix of comparison data

	Ec1	Ec2	Ec3	Ec4
Ec1	1	5.2609	3.6232	2.9420
Ec2	0.1901	1	0.8455	0.7890
Ec3	0.276	1.1827	1	1.4741
Ec4	0.3399	1.2675	0.6784	1
Sum	1.8060	8.7110	6.1471	6.2051

Table 5.10: Output 2: Normalized matrix and calculated weighting values

	Ec1	Ec2	Ec3	Ec4	Sum	Weighting
Ec1	0.5537	0.6039	0.5894	0.4741	2.2211	0.5553
Ec2	0.1052	0.1148	0.1376	0.1271	0.4847	0.1212
Ec3	0.1528	0.1358	0.1627	0.2376	0.6888	0.1722
Ec4	0.1882	0.1455	0.1104	0.1612	0.6052	0.1513
Sum	1	1	1	1	4	1

Table 5.11: Calculation of λmax

	Ec1	Ec2	Ec3	Ec4	W	R	λmax
Ec1	1	5.2609	3.6232	2.9420	0.5553	4.0733	4.0458
Ec2	0.1901	1	0.8455	0.7890	0.1212	4.0576	
Ec3	0.276	1.1827	1	1.4741	0.1722	4.0174	
Ec4	0.3399	1.2675	0.6784	1	0.1513	4.0347	

Table 5.12: Calculation of CI and CR

n	λmax	CI	R	CR
4	4.0458	0.015	0.90	0.017

5.6.4 Weighting calculation of social criteria

The total number of responses received was 46 comparing the social criteria against the significance to the total impact caused by the social aspect. Based on their average values, a matrix of comparison data was developed and it is shown in Table 5.13 (Output 1). Note that the symbols Sc1, Sc2, Sc3 and Sc4 represent four social criteria. The normalized matrix based on the Output 1 data is shown in Table 5.14 with the calculated values of weighting of each criterion. Table 5.15 shows how λ_{max} is calculated according to the data of the normalized matrix and the derived weighting values. The R value related to the current problem is 0.90 due to the size of matrix being equal to 4. Table 5.16 gives the numerical illustration of the calculation of CI and CR values. Both values are less than 0.1, confirming the consistency of pair-wise data used in the current situation on either criterion, CI or CR.

Table 5.13: Output 1: Matrix of comparison data

	Sc1	Sc2	Sc3	Sc4
Sc1	1	1.7739	3.0580	2.9217
Sc2	0.5637	1	3.3188	3.0406
Sc3	0.3270	0.3013	1	1.8594
Sc4	0.3423	0.3289	0.5378	1
Sum	2.2330	3.4041	7.9146	8.8217

Table 5.14: Output 2: Normalized matrix and calculated weighting values

	Sc1	Sc2	Sc3	Sc4	Sum	Weighting
Sc1	0.4478	0.5211	0.3864	0.3312	1.6865	0.4216
Sc2	0.2524	0.2938	0.4193	0.3447	1.3102	0.3276
Sc3	0.1464	0.0885	0.1263	0.2108	0.5721	0.1430
Sc4	0.1533	0.0966	0.0680	0.1134	0.4312	0.1078
Sum	1	1	1	1	4	1

Table 5.15: Calculation of λmax

	Sc1	Sc2	Sc3	Sc4	W	R	λmax
Sc1	1	1.7739	3.0580	2.9217	0.4216	4.1624	4.1112
Sc2	0.5637	1	3.3188	3.0406	0.3276	4.1754	
Sc3	0.3270	0.3013	1	1.8594	0.1430	4.0556	
Sc4	0.3423	0.3289	0.5378	1	0.1078	4.0515	

Table 5.16: Calculation of CI and CR

n	λmax	CI	R	CR
4	4.1112	0.037	0.90	0.041

5.6.5 Weighting calculation of functional criteria

The total number of responses received was 46 comparing the functional criteria against the significance to the total impact caused by the functional aspect. Based on their average values, a matrix of comparison data was developed and it is shown in Table 5.17 (Output 1). Note that the symbols Fn1, Fn2 and Fn3 represent three functional criteria. The normalized matrix based on the Output 1 data is shown in Table 5.18 with the calculated values of weighting of each criterion. Table 5.19 shows how λ_{max} is calculated according to the data of the normalized matrix and the derived weighting values. The R value related to the current problem is 0.58 due to the size of matrix being equal to 3. Table 5.20 gives the numerical illustration of the calculation of CI and CR values. Both values are less than 0.1, confirming the consistency of pair-wise data used in the current situation on either criterion, CI or CR.

Table 5.17: Output 1: Matrix of comparison data

	F1	F2	F3
F1	1	1.9620	1.5695
F2	0.5097	1	1.2693
F3	0.6371	0.7878	1
Sum	2.1468	3.7499	3.8388

Table 5.18: Output 2: Normalized matrix and calculated weighting values

	F1	F2	F3	Sum	Weighting
F1	0.4658	0.5232	0.4088	1.3979	0.4660
F2	0.2374	0.2667	0.3306	0.8347	0.2782
F3	0.2968	0.2101	0.2605	0.7674	0.2558
Sum	1	1	1	3	1

Table 5.19: Calculation of λmax

	F1	F2	F3	W	R	λmax
F1	1	1.9620	1.5695	0.4660	3.0332	3.0237
F2	0.5097	1	1.2693	0.2782	3.0204	
F3	0.6371	0.7878	1	0.2558	3.0176	

Table 5.20: Calculation of CI and CR

n	λmax	CI	R	CR
3	3.0237	0.012	0.58	0.021

5.7 Summary of findings from Questionnaire 2

The second industry-wide questionnaire survey was undertaken to capture the pair-wise comparison data from which the research planned to calculate the weighting values of aspects and their criteria. Accordingly, weighting values for four sustainable aspects were obtained, as shown in Table 5.21. The values show that the environmental aspect is the most significant aspect for the sustainable management of community buildings from the perspective of local council professionals. Starting with the environmental aspect, the significance decreases in the order of economic aspect to social aspect and finally to functional aspect.

Similarly, the weighting values for environmental criteria were also captured and they are shown in Table 5.22. According to the results, the most significant environmental criterion is “water management”, whereas the least significant is “usage of hazardous goods and materials”. Tables 5.23 to 5.25 show the weighting values of criteria related to economic, social and functional aspects. According to the results, the most significant economic criterion is “life cycle cost” while “local community engagement” is most significant for the social criteria and “impact of failure and response” for the functional criteria. Likewise, the least significant criteria under economic, social and functional aspects are “land value”, “employee well-being” and “compliance to building standards and regulations”, respectively.

Table 5.21: Weighting values of sustainable aspects

Aspect	Weighting
Environmental	0.3691
Economic	0.2712
Social	0.1845
Functional	0.1752

Table 5.22: Weighting values of environmental criteria

Criteria	Weighting
En 1= Water management	0.2304
En 2= Material sustainability	0.2111
En 3= Energy efficiency	0.2148
En 4= Waste management	0.1177
En 5= Air and noise pollution	0.0829
En 6= User comfort	0.0793
En 7= Usage of hazardous goods and materials	0.0637

Table 5.23: Weighting values of economic criteria

Criteria	Weighting
Ec 1= Life cycle cost	0.5553
Ec 2= Land value	0.1212
Ec 3= Local economy	0.1722
Ec 4= Additional capital investment	0.1513

Table 5.24: Weighting values of social criteria

Criteria	Weighting
Sc 1= Local community engagement	0.4216
Sc 2= Community benefits and equity	0.3276
Sc 3= Neighbourhood character	0.1430
Sc 4= Employee well-being	0.1078

Table 5.25: Weighting values of functional criteria

Criteria	Weighting
Fn 1= Impact of failure and response	0.4660
Fn 2= Minimum level of service	0.2782
Fn 3= Compliance to building standards and regulations	0.2558

6 DEVELOPMENT OF THE DECISION-MAKING MODEL

6.1 Introduction

Once the comprehensive decision-making hierarchical structure had been developed, the next important task was to utilize it in making sustainable decisions. The hierarchical structure led to the evaluation of the sustainability impact (sustainability index) caused by a given building component. Knowing the sustainability impact makes it easier for asset managers to prioritise maintenance activities. Two parameters, weighting and individual impact, are involved in the evaluation of the sustainability index. Chapter 5 focused on calculating the weighting values of criteria and aspects. Therefore the task of assigning impact values to criteria for different building components is described in detail in this chapter. As the problem was based on two parameters (weighting and individual impact), two analytical techniques were required for solutions. AHP was the first analytical technique applied and the neuro fuzzy system was the second. The research developed a decision-making model based on two methods incorporating these two analytical techniques. One method's working platform was common spread sheet mathematical calculations and the other method required MatLab software, apart from common mathematical calculations. In this chapter, both methods are explained in detail, and they are illustrated where necessary.

6.2 Using Analytical Hierarchy Process (AHP)

The required outcome of the model is the solution to how the overall sustainability impact of a given building component is evaluated. To understand the bigger picture of the evaluation, it is important to be aware of the hierarchical structure of sustainable building management. The hierarchical structure is comprised of three levels and the evaluation proceeded in two stages. The first stage concerned how to reach the level of aspects through criteria, whereas the second stage concerned the level of corporate sustainability by separate aspects. In both stages the evaluations relied on two depending parameters: weighting and individual impact. Weighting was outlined in Section 5.3.1 and a detailed analysis of weighting calculation was presented in Section 5.3.5. Therefore, more weight is given to individual impact in this section.

Impact is intangible to measure and purely quantitative assessment is not viable. This creates situations with more uncertainty in which fuzzy logic is undoubtedly more appropriate other than any theory. In this case, linguistic terms act as variables to define the impact relevant to the selected criterion. Most importantly, they carry membership functions over the selected range of universe of discourse and the range assigned to the linguistic variable can be incorporated with their definition. This provides a good solution to minimise the subjectivity and uncertainty of the common behaviour of impact.

6.2.1 Linguistic definition of input variables

The evaluation consists of two stages as mentioned above. Hence, output variables of the first stage are input variables of the second stage. For example, in the first stage, seven environmental criteria are input variables which are combined to evaluate the output of total environmental impact. The second stage evaluates the total sustainability impact from the total impacts caused by four sustainability aspects. Hence, the total environmental impact evaluated in Stage 1 becomes one input for Stage 2. It is clear that Stage 2 is dependent on Stage 1. Therefore, direct inputs are only required for Stage 1. The first step in assigning impact values by criteria is to identify the impact using linguistic terms. As in most fuzzy applications, the present research recommends using five linguistic terms incorporating a number range of 1 to 5. The five linguistic terms are “Very low”, “Low”, “Medium”, “High” and “Very high”. Unlike the weighting, the impact of any criterion distinctively varies on building components. Hence, a clear definition linked to each impact level minimises the extent of subjectivity inherent in the impact value.

However, the model in either method is common to every local council in Australia. Therefore, the meaning of each linguistic term can be calibrated to suit different local councils or contexts. For example, for definitions under the criterion of “Water management”, one council may define the term as referring to the percentage of water consumption in the function of the building component. Moreover, if the building component only uses water out of the total consumables of its function then the percentage of water consumption is 100%. In that way, the building component is critical for the criterion of “water management”, which creates a “very high” impact on the criterion. Extending the idea and depending on the perceptions of the councils, threshold percentages can be maintained in the definitions. For example, more than 50% for “Very high”, 30% to 50% for “High”, 10% to 30% for “Medium”, 0% to 10% for “Low” and No water usage at all for “Very low”. Another way that councils may define the term is by providing specific volumes of water consumption for each impact level. For example; if x or more volume of water is used by the building component daily, then it causes a “very high” impact on the criterion. Similarly, building components with a range of y to z daily usage of volume of water may be described as causing “Low” impact. Same principle will be applied to other impacts of “Medium”, “Low” and “Very high”.

Another criterion, “Waste management”, may further assist with clarification. The idea of using percentages can also be applied to this criterion. For instance, the percentage of non-recyclable waste generation from the function can be considered. In accordance with the definition, some councils may create a threshold percentage; say 50%, for assigning “Very high” impact. They may follow the same principle for the other impact terms, such that 30% to 50% is allocated for “High”, 10% to 30% for “Medium”, 0% to 10% for “Low” and no waste generation for “Very low”. In a different definition system, some councils may calculate a threshold non-recyclable quantity for waste generation rather than a percentage.

Having gone through the process of giving definitions to linguistic terms, it is obvious that the process may vary among local councils. Local councils have different perceptions on maintaining standards. Therefore, fixed definitions are difficult to use in the application. However, the present research has clearly delivered the concept of how they are measured and further research is required. This is planned in the next phase of the industrial project, which is to implement the developed software in partner councils.

6.2.2 Membership functions for input variables and output variables (Evaluation Stage 1)

Once linguistic terms are defined, the next step is to develop membership functions (or fuzzy sets) of those linguistic terms related to their criteria. Impacts of the criteria represented by linguistic terms are the input variables to the output variable, which is the impact of the related aspect. Hence, four output variables and their input variables were the subjects of the evaluation in Stage 1. Table 6.1 provides a clear picture of the four scenarios of outputs and their related inputs.

Table 6.1: Output scenarios of the evaluation Stage 1

Output Scenario	Output Variable	Input Variables
Output 1	Environmental Impact	1. Water management 2. Material sustainability 3. Energy efficiency 4. Waste management 5. Air and noise pollution 6. User comfort 7. Usage of hazardous goods and materials
Output 2	Economic Impact	1. Life cycle cost 2. Land value 3. Local economy 4. Additional capital investment
Output 3	Social Impact	1. Local community engagement 2. Community benefits and equity 3. Neighborhood character 4. Employee well-being
Output 4	Functional Impact	1. Impact of failure and response 2. Minimum level of service 3. Compliance to building standards and regulations

Triangular membership functions were assigned to each input and output variables and the range of universe of discourse was taken as varying from 1 to 5. Membership functions of all input and output variables corresponded with the impact value. Therefore, similar membership functions were allocated for each. Accordingly, fuzzy sets were defined for the membership functions “very low”, “low”, “medium”, “high” and “very high” and their graphical representation is given in Figure 6.1.

Fuzzy set A (Very Low)   A= (1,1),(2,0),(3,0),(4,0),(5,0)

Fuzzy set B (Low)   B= (1,0),(2,1),(3,0),(4,0),(5,0)

Fuzzy set C (Medium)   C= (1,0),(2,0),(3,1),(4,0),(5,0)

Fuzzy set D (High)   D= (1,0),(2,0),(3,0),(4,1),(5,0)

Fuzzy set E (Very High)   E= (1,1),(2,0),(3,0),(4,0),(5,1)

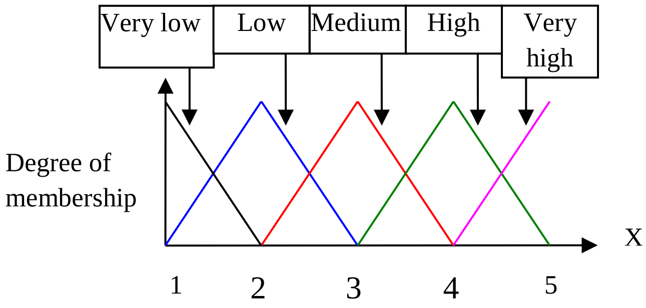


Figure 6.1: Membership functions for input and output variables

6.2.3 Membership functions for input variables and the output variable (Evaluation Stage 2)

Output variables of the previous stage become the input variables for the next stage. Therefore, the input variables are:

- Environmental Impact
- Economic Impact
- Social Impact
- Functional Impact

Their membership functions are similar to those in Stage 1 represented by fuzzy sets and Figure 6.1.

6.2.4 Impact vs. Condition

Although impact can be measured linguistically, the research discovered an intuitive fact that the impact varies according to the condition of the building component. The relationship of the two parameters is inversely proportional, as the better the condition, the lower the impact. For example, the impact for a given building component is higher at its worst condition (condition 5) compared to the impact of the same building component at its best condition. However, the correct trend of the variation is unknown, but educated guesses for the trend can be made depending on the purpose of the study. The main purpose of the use of impact values is for prioritising building components for maintenance activities. Therefore, the actual trend is not compulsorily required due to the comparison aspect, as the guessed trend has no effect on the result of the study. Linear variation is the simplest calculation method for the guessed trend. As a result, the present study gave a linear variation for the graph of Impact vs. Condition.

In practice, the, extreme ends of a situation are more clearly identifiable than any intermediate event in between. The same scenario applies to the impact when it is assigned according to the condition. Accordingly, two extreme ends are the impacts of a given building component at the best and worst conditions. In between, impact values vary linearly, which is shown in Figure 6.24. Accordingly, the impact value at any given condition (current condition is targeted in the present study) can be calculated by the following equation.

$$I=\frac{(M-N)\times(C-1)}{4}+N$$

................Equation 6.1

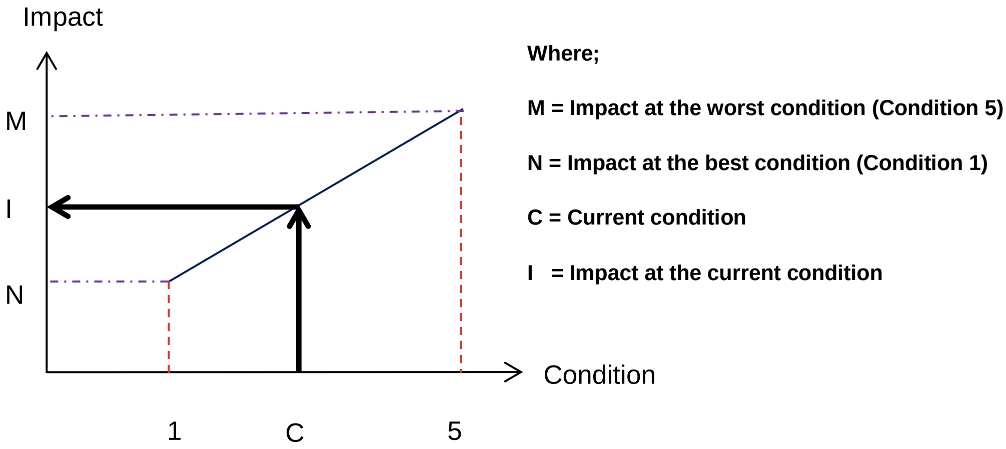


Figure 6.2: The Graph of Impact vs. Condition

6.2.5 Stage 1-Calculation of total impact caused by a given building component through a given sustainable aspect

As stated above, the total impact caused by a given building component through a given sustainable aspect is linked with their associated criteria, which can be interpreted as input variables to the total impact through the given aspect. Moreover, two parameters, weighting and the individual impact, affect the value of each input criterion. The aggregate effect of each criterion is called the weighted impact of the building component caused by the given criterion. The weighted impact can be calculated by the multiplication of both parameters of weighting and the individual impact. The general equation for the calculation of weighted impact related to a given criterion is shown in Equation 6.2. The aggregation of the calculated weighted impact values provides the total impact of the given building component through the given aspect. This can be obtained through the summation of those values, as shown by Equation 6.3.

$$I_{Cwi}=w_{Ci}\times I_{Ci}$$

................Equation 6.2

$$I_A = \sum_{i=1}^{n} w_{Ci} \times I_{Ci}$$

................Equation 6.3

where,

I_{Cwi}= weighted impact caused through the criterion i;

W_{Ci}= weighting of the criterion i;

I_{Ci} = Individual impact caused by the criterion i;

n = total number of criteria for the aspect;

I_A = Total impact of aspect A

Calculation of the total environmental impact

In relation to the environmental criteria, let the weighting values and the impact values for the given building component be represented by Table 6.2. Note that environmental criteria are denoted by En1, En2, En3, En4, En5, En6 and En7 and the current condition of the building component is assumed to be C.

Table 6.2: Given weighting and impact values related to environmental criteria

Criterion	Weighting	Impact caused by the building component when it is at the best condition (Condition 1)	Impact caused by the building component when it is at the worst condition (Condition 5)
En1	W1	N1	M1
En2	W2	N2	M2
En3	W3	N3	M3
En4	W4	N4	M4
En5	W5	N5	M5
En6	W6	N6	M6
En7	W7	N7	M7

According to the impact values shown in Table 6.3, the impact of the building component at its current condition can be calculated using Equation 6.1. Weighted impact values can be computed using Equation 6.2 by multiplying the previously obtained values by the weighting values. The view of the calculations is illustrated in Table 6.3.

Table 6.3: Calculation of impact values at the current condition and weighted impact values

Criterion	Impact caused by the building component at its current condition $I_{Ci}=\frac{(M-N)\times(C-1)}{4}+N$	Weighted impact $I_{Cwi}=w_{Ci}\times I_{Ci}$
En1	$\frac{(M1-N1)\times(C-1)}{4}+N1$	$\left[\frac{(M1-N1)\times(C-1)}{4}+N1\right]\times W1$
En2	$\frac{(M2-N2)\times(C-1)}{4}+N2$	$\left[\frac{(M2-N2)\times(C-1)}{4}+N2\right]\times W2$
En3	$\frac{(M3-N3)\times(C-1)}{4}+N3$	$\left[\frac{(M3-N3)\times(C-1)}{4}+N3\right]\times W3$
En4	$\frac{(M4-N4)\times(C-1)}{4}+N4$	$\left[\frac{(M4-N4)\times(C-1)}{4}+N4\right]\times W4$
En5	$\frac{(M5-N5)\times(C-1)}{4}+N5$	$\left[\frac{(M5-N5)\times(C-1)}{4}+N5\right]\times W5$
En6	$\frac{(M6-N6)\times(C-1)}{4}+N6$	$\left[\frac{(M6-N6)\times(C-1)}{4}+N6\right]\times W6$
En7	$\frac{(M7-N7)\times(C-1)}{4}+N7$	$\left[\frac{(M7-N7)\times(C-1)}{4}+N7\right]\times W7$

Hence, the total environmental impact is given by the total sum of the column of weighted impact. Let that value be denoted by I_{En} (Equation 6.4).

Total Environmental Impact= I_{En}

................Equation 6.4

Calculation of the total economic impact

Similar to the environmental impact calculation, the weighting values and impact values for the given building component on economic criteria are represented by Table 6.4. Note that economic criteria are denoted by Ec1, Ec2, Ec3 and Ec4, and the current condition of the building component is assumed to be C.

Table 6.4: Given weighting and impact values related to economic criteria

Criterion	Weighting	Impact caused by the building component when it is at the best condition (Condition 1)	Impact caused by the building component when it is at the worst condition (Condition 5)
Ec1	W1	N1	M1
Ec2	W2	N2	M2
Ec3	W3	N3	M3
Ec4	W4	N4	M4

According to the impact values shown in Table 6.4, the impact of the building component at its current condition can be calculated using Equation 6.1. Weighted impact values can be computed using Equation 6.2 by multiplying the previously obtained values by the weighting values. The calculations are shown in Table 6.5.

Table 6.5: Calculation of impact values at the current condition and weighted impact values

Criterion	Impact caused by the building component at its current condition $I_{Ci}=\frac{(M\text{-}N)\times(C\text{-}1)}{4}+N$	Weighted impact $I_{Cwi}=w_{Ci}\times I_{Ci}$
Ec1	$\frac{(M1\text{-}N1)\times(C\text{-}1)}{4}+N1$	$\left[\frac{(M1\text{-}N1)\times(C\text{-}1)}{4}+N1\right]\times W1$
Ec2	$\frac{(M2\text{-}N2)\times(C\text{-}1)}{4}+N2$	$\left[\frac{(M2\text{-}N2)\times(C\text{-}1)}{4}+N2\right]\times W2$
Ec3	$\frac{(M3\text{-}N3)\times(C\text{-}1)}{4}+N3$	$\left[\frac{(M3\text{-}N3)\times(C\text{-}1)}{4}+N3\right]\times W3$
Ec4	$\frac{(M4\text{-}N4)\times(C\text{-}1)}{4}+N4$	$\left[\frac{(M4\text{-}N4)\times(C\text{-}1)}{4}+N4\right]\times W4$

Hence, the total economic impact is given by the total sum of the column of weighted impact. Let that value be denoted by I_{Ec} (Equation 6.5).

Total Economic Impact= I_{Ec}

................Equation 6.5

Calculation of the total social impact

Similar to the previous aspects, weighting values and impact values for the given building component on social criteria are given by Table 6.6. Social criteria are denoted by Sc1, Sc2, Sc3 and Sc4, and the current condition of the building component is assumed to be C.

Table 6.6: Given weighting and impact values related to social criteria

Criterion	Weighting	Impact caused by the building component when it is at the best condition (Condition 1)	Impact caused by the building component when it is at the worst condition (Condition 5)
Sc1	W1	N1	M1
Sc2	W2	N2	M2
Sc3	W3	N3	M3
Sc4	W4	N4	M4

According to the impact values shown in Table 6.6, the impact of the building component at its current condition can be calculated using Equation 6.1. This is followed by computing weighted impact values using Equation 6.2. The calculations are illustrated in Table 6.7.

Table 6.7: Calculation of impact values at the current condition and weighted impact values

Criterion	Impact caused by the building component at its current condition $I_{Ci}=\frac{(M-N)\times(C-1)}{4}+N$	Weighted impact $I_{Cwi}=w_{Ci}\times I_{Ci}$
Sc1	$\frac{(M1-N1)\times(C-1)}{4}+N1$	$\left[\frac{(M1-N1)\times(C-1)}{4}+N1\right]\times W1$
Sc2	$\frac{(M2-N2)\times(C-1)}{4}+N2$	$\left[\frac{(M2-N2)\times(C-1)}{4}+N2\right]\times W2$
Sc3	$\frac{(M3-N3)\times(C-1)}{4}+N3$	$\left[\frac{(M3-N3)\times(C-1)}{4}+N3\right]\times W3$
Sc4	$\frac{(M4-N4)\times(C-1)}{4}+N4$	$\left[\frac{(M4-N4)\times(C-1)}{4}+N4\right]\times W4$

Hence, the total social impact is given by the total sum of the column of weighted impact. Let that value be denoted by I_{Sc} (Equation 6.6).

Total Social Impact= I_{Sc}

................Equation 6.6

Calculation of the total functional impact

A similar calculation is adopted for the total functional impact. As the first step, weighting values and impact values for the given building component are given in Table 6.8. Fn1, Fn2 and Fn3 represent functional criteria. The current condition of the building component is assumed to be C.

Table 6.8: Given weighting and impact values related to functional criteria

Criterion	Weighting	Impact caused by the building component when it is at the best condition (Condition 1)	Impact caused by the building component when it is at the worst condition (Condition 5)
Fn1	W1	N1	M1
Fn2	W2	N2	M2
Fn3	W3	N3	M3

According to the impact values shown in Table 6.8, the calculation of the impact of the building component at its current condition using Equation 6.1 is followed by the calculation of the weighted impact values using Equation 6.2. The calculations are illustrated in Table 6.9.

Table 6.9: Calculation of impact values at the current condition and weighted impact values

Criterion	Impact caused by the building component at its current condition $I_{Ci}=\frac{(M\text{-}N)\times(C\text{-}1)}{4}+N$	Weighted impact $I_{Cwi}=w_{Ci}\times I_{Ci}$
Fn1	$\frac{(M1\text{-}N1)\times(C\text{-}1)}{4}+N1$	$\left[\frac{(M1\text{-}N1)\times(C\text{-}1)}{4}+N1\right]\times W1$
Fn2	$\frac{(M2\text{-}N2)\times(C\text{-}1)}{4}+N2$	$\left[\frac{(M2\text{-}N2)\times(C\text{-}1)}{4}+N2\right]\times W2$
Fn3	$\frac{(M3\text{-}N3)\times(C\text{-}1)}{4}+N3$	$\left[\frac{(M3\text{-}N3)\times(C\text{-}1)}{4}+N3\right]\times W3$

Hence, the total functional impact is given by the total sum of the column of weighted impact. Let that value be denoted by I_{Fn} (Equation 6.7).

Total Functional Impact= I_{Fn}

.................Equation 6.7

6.2.6 Stage 2- Calculation of the total sustainability impact caused by a given building component

As stated above, the output variable of the evaluation Stage 2 is the value of the total sustainability impact of the given building component, whereas its input variables are the impact values of four sustainable aspects. Two parameters (weight and individual impact) are again combined and used, as in Stage 1, to obtain the final output value of Stage 2, which is the total sustainability impact. However, the individual impact values of four sustainable aspects have already been obtained from the results of Stage 1, and they are shown by Equations 6.4 to 6.7. The weightings of the four aspects were obtained in Section 5.6.1. Therefore, the weighted impact of each aspect can be calculated by modifying Equation 6.2 in relation to the aspects. The new equation is shown by Equation 6.8. The total sum of the weighted impact values of each aspect is the total sustainability impact for the given building component. In this case, Equation 6.9 was created to calculate the total sustainability impact. It is a slight modification of Equation 6.3, replacing aspect data in place of criterion data.

$I_{Awi}=w_{Ai}\times I_{Ai}$

.................Equation 6.8

$$I_S=\sum_{i=1}^{n} w_{Ai}\times I_{Ai}$$

................Equation 6.9

where,

I_{Awi} = weighted impact caused through the Aspect i;

W_{Ai} = weighting of the aspect i;

I_{Ai} = Individual impact of aspect i;

n = total number of aspects (=4);

I_S = total sustainability impact

According to the model, I_{Ai} values for four aspects are I_{En}, I_{Ec}, I_{Sc} and I_{Fn} as per Equations 6.4 to 6.7. W_{Ai} values can be taken from Table 5.23 shown in Section 5.6.1. Hence, total sustainability impact (I_s) can be calculated by substituting those values in Equation 6.9.

6.2.7 Overview of the total process using AHP

Figure 6.3 shows the overview of the evaluation process explained above. A mathematical demonstration is given for the calculation of functional impact (I_{Fn}), and similar demonstrations can be used to show the calculation of other impacts (I_{En}, I_{Ec} and I_{Sc}). According to the figure, individual impact values related to each functional criterion are assigned. They are multiplied by the related weightings and their total summation gives the total functional impact, I_{Fn}. A similar process can be adopted to find I_{En}, I_{Ec} and I_{Sc}. To this point, all calculations are related to Stage 1. In Stage 2, all calculated total impact values of four sustainable aspects are multiplied by their related weightings. The sum of those multiplications gives the total sustainability impact value (Sustainability index) of the given building component.

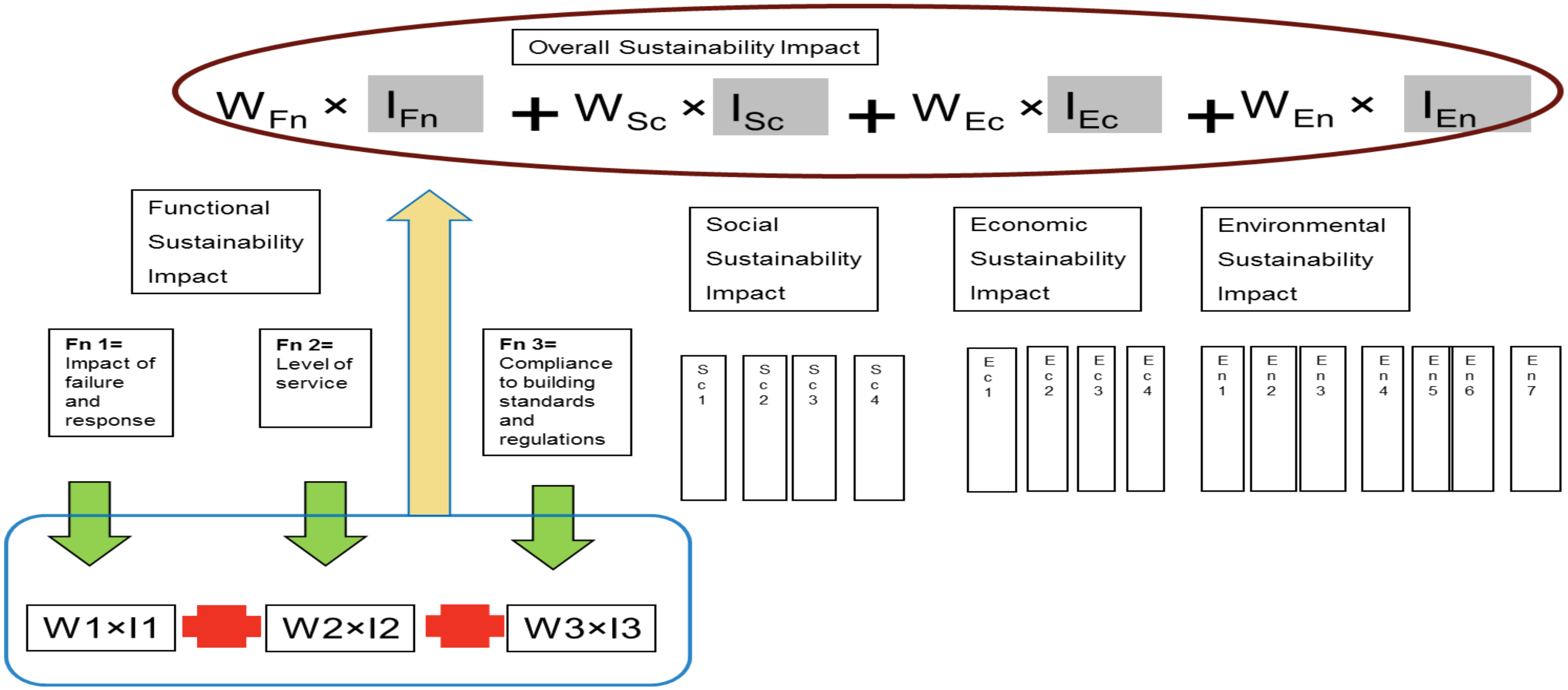


Figure 6.3: Overview of the evaluation process using AHP

6.3 Using a combined AHP and Neuro- Fuzzy System

6.3.1 Background

One approach to solutions to the type of problems investigated here can be the application of AHP for weighting calculations and fuzzy logic incorporating linguistic terms for performance calculations. This was the method adopted in the previous approach. Another possibility is using Artificial Intelligence (AI) applications, particularly fuzzy logic systems, because they can deal with linguistic variables and fuzzy if-then rules. Neuro fuzzy systems are much better, because they are not only using fuzzy logic systems but they are also capable of learning applied in artificial neural network (ANN). However, since the current problem does not give a tangible solution, the inclusion of a learning process is not feasible. In a neural network problem, weightings or degrees of support (DoSs) of input variables to the output variable have a large effect on the final solution. In learning and training data processes, the system tries to produce weighting values which can give a standard solution to the output based on input variables. Therefore, if the actual weighting is known, and the weighting values can be involved in fuzzy if-then rules, this is a reliable solution to intangible problems. Hence, the researcher used a partly Neuro fuzzy system in one stage of the model's evaluation.

Whichever approach is chosen, the evaluation must cover two stages. Stage 1 was to elicit the total impact related to each aspect of the related criteria. With the exception of the environmental aspect, all other aspects are represented by three or four criteria. A careful investigation of fuzzy logic applications in the research literature showed that the studies are mostly limited to four input variables or less if they are assigned more linguistic terms. The reason may be that it will cause a large number of if-then rules which are not capable of being practically handled if that threshold is exceeded. In relation to the evaluation of the environmental impact, there are seven input variables, and they are represented by five linguistic terms: very low, low, medium, high and very high. The minimum number of if-then rules is basically generated by expert judgement of which "then" outcome is developed according to the given "if" inputs. The minimum number of rules for this problem is 78125, which was calculated by 5^7. Therefore, a fuzzy logic approach is not practical for the evaluation of environmental impact and the approach was not applied in Stage 1. Instead, the AHP approach was utilised for Stage 1 in this method, similar to the previous method.

In contrast, Stage 2 had four input variables to evaluate the output and all variables were represented by five linguistic terms: very low, low, medium, high and very high. If experts to elicit “then” opinions of input combinations then; the minimum number of rules is 625 which, was calculated by 5^4. This was a large number and the research team found that even experts could not correctly judge the solutions to the combinations of some rules. The expert thought process is another strategy which can be utilised to develop rules. One approach in that strategy is to ignore the weightings of input variables and then develop all derivable rules. In this regard, the maximum number of rules can be derived by the calculation of $5^{5,}$ which is 3125. Even though this approach did not involve experts, some rules were found to be completely unrealistic. For example, each input variable was assigned a very high impact in one rule but its consequence was very low in terms of total sustainability impact. This gave rise to a problem with lack of reliability of the solution.

A better approach to using the strategy of expert thought process is developing rules based on assigned weights of input variables. In this situation, the degree of support (DoS) of the output solution by inputs was the main criterion followed in rule development. Accordingly, all rules with DoS=0 were eliminated and others were taken into the rule block. According to the author’s knowledge, there is no standard method in the literature to exactly determine the number of rules. Instead the method involves manually entering and accordingly determining the number. Based on the concepts used in probability theorem, the author derived the following equation (Equation 6.10) to determine the effective number of rules related to the current problem. Accordingly, a total of 1845 rules were derived and the author obtained the same number of rules by manually entering. The author also applied the same principles and created new equations for determining the effective number of rules for other studies. The results verified the credibility of the author’s innovative approach by obtaining the same results using both approaches: manual entry and using the equation.

Effective number of rules =
$[^4C_4+^4C_3\times^4P_1+^4C_2\times(^4P_2+^4P_1)+^4C_3\times(^4P_3+^4P_1\times^3C_1\times^3P_1+^4P_1)]\times^5P_1$

.................Equation 6.10

6.3.2 Systematic approach of Neuro-Fuzzy application

A Neuro fuzzy model was developed on the platform of Matlab software (MATLAB R 2012b). The Mamdani method was the fuzzy inference system (FIS) used in the program. Max-Min was selected for applying the implication and aggregation of rules because of the wider applicability and easier graphical interpretation (Jang, 1997). Centre of Area (CoA) was the selected method of doing defuzzification. The basic structure of the Neuro fuzzy system is shown in Figure 6.4, which shows all input variables, output variables and FIS application. The next step was to develop membership functions of each input variable and the output variable. They are shown in Figures 6.5 to 6.9.

The next step was to develop the rule block for four input variables and the output variable. The DoS was assigned to each rule and they were correlated with rule implications and aggregation. The final fuzzified result was then converted to a real value using the CoA defuzzification method. This is the process inside the model but in practice, it is only necessary to assign previously obtained values from Stage 1 (I_{En}, I_{Ec}, I_{Sc} and I_{Fn}) as input variables. Accordingly, the model delivers the value of the final output, which measures the total sustainability impact caused by the given building component. Figure 6.10 shows the value of the sustainability index according to given input values. The figure also illustrates the way that inference occurs according to the input values using some rules of the total rule block (1845 rules). The total rule block is provided in Appendix D with the related DoS values. Finally, Figure 6.11 illustrates the surface view of the output in a three-dimensional space, which explains how the output varies according to the input variables. The system view requires fixing the value of two input variables in order to interpret the output in three dimensions.

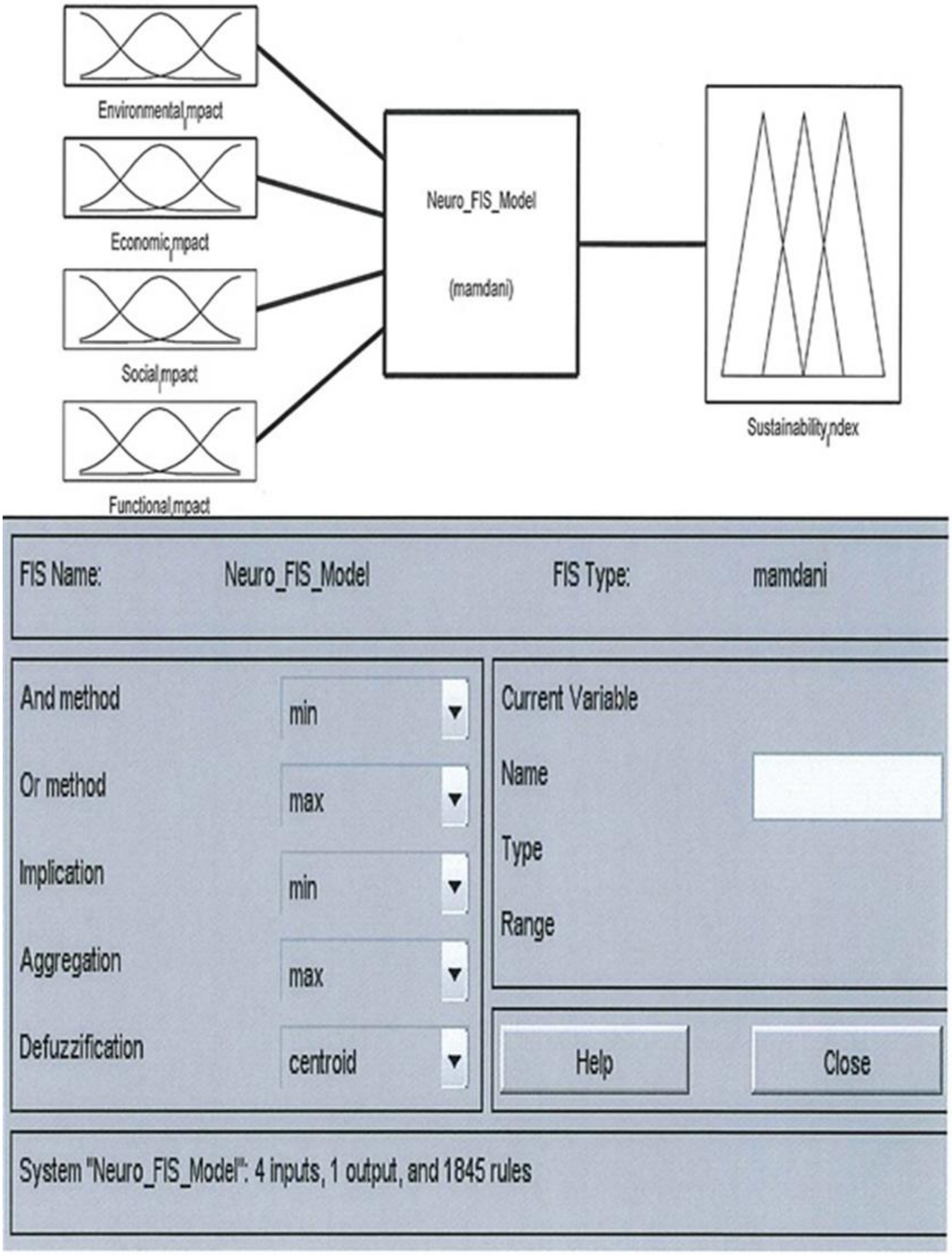


Figure 6.4: Structure of the Neuro fuzzy model

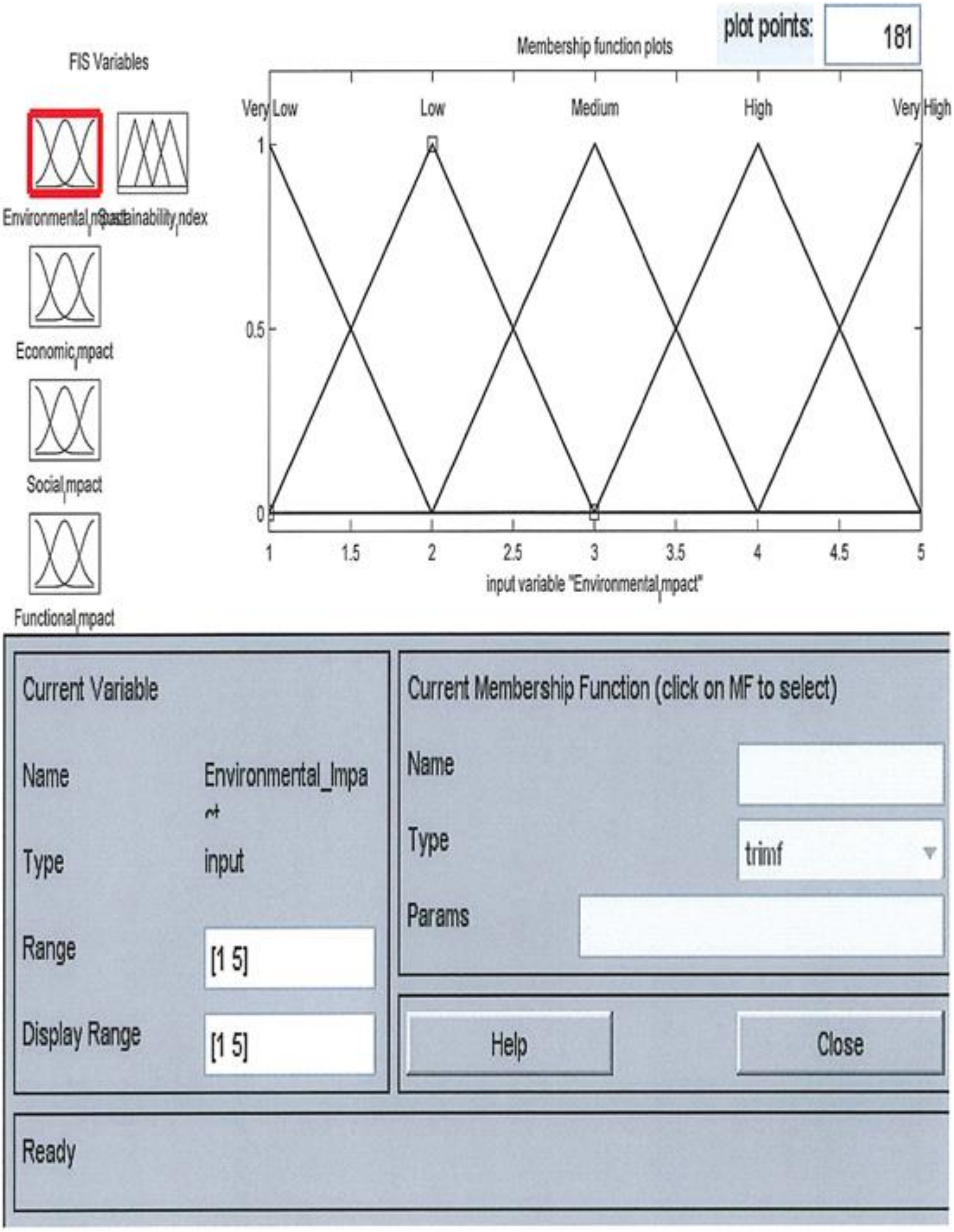


Figure 6.5: Membership functions of the input variable of environmental Impact

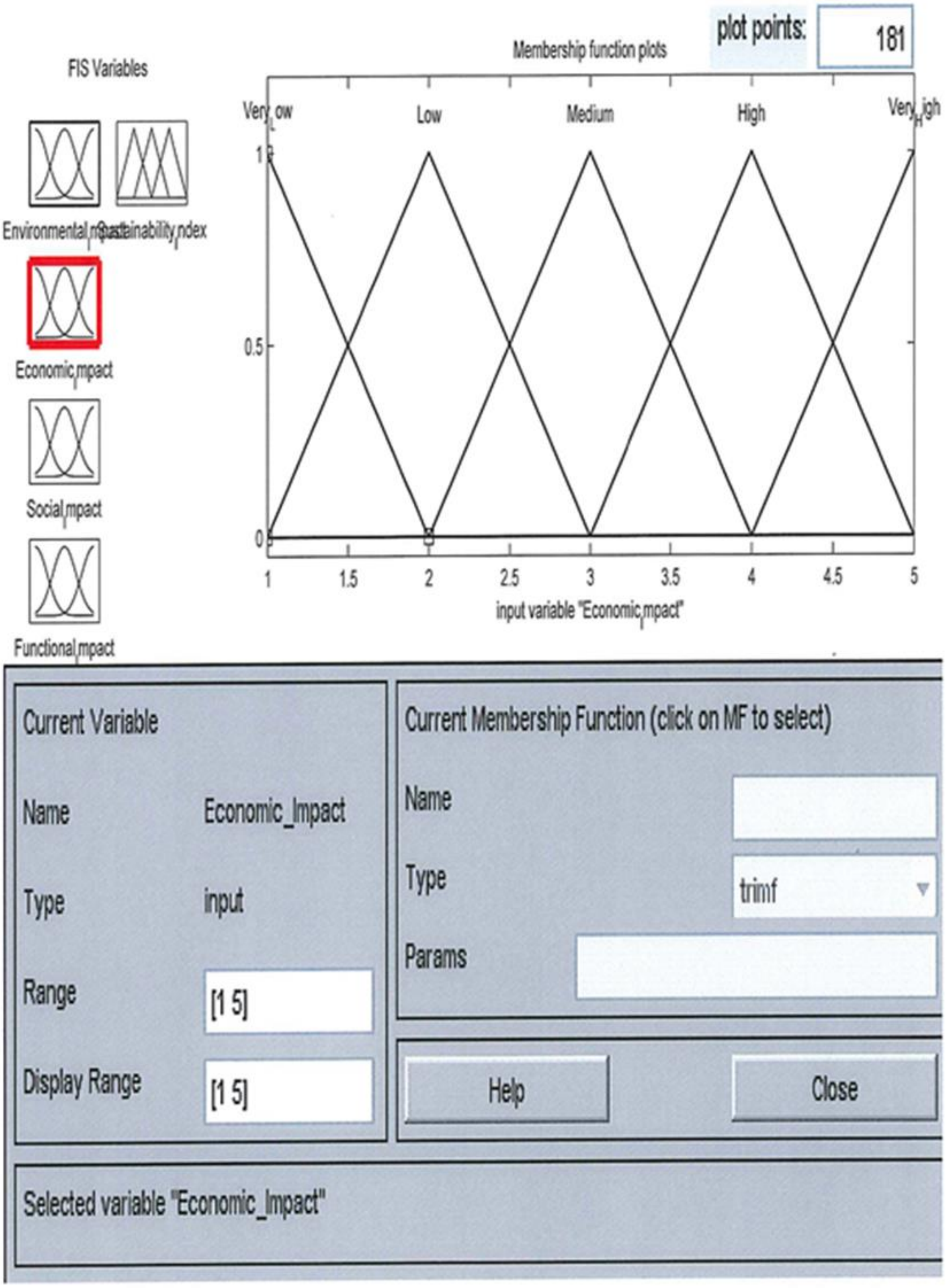


Figure 6.6: Membership functions of the input variable of economic Impact

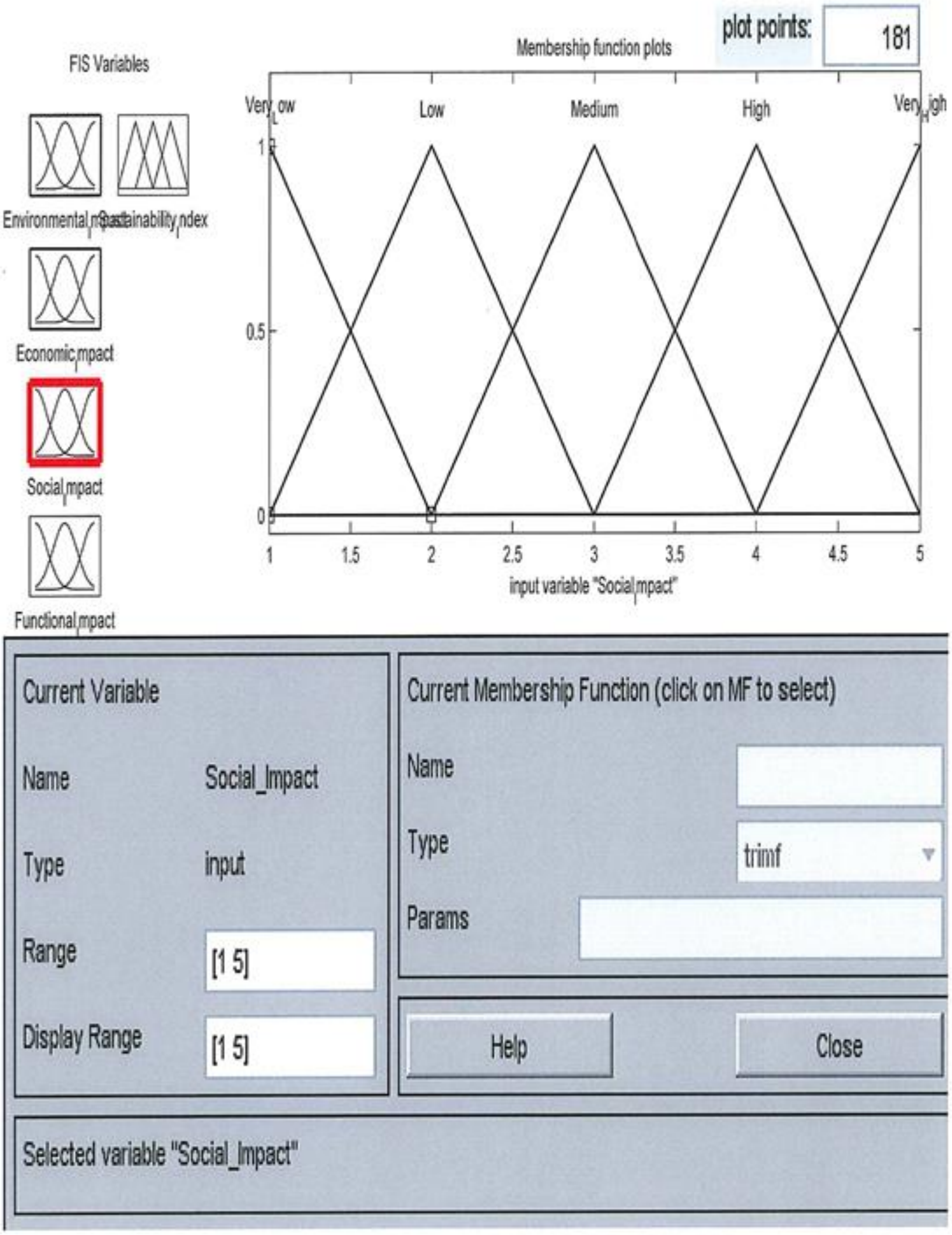


Figure 6.7: Membership functions of the input variable of social Impact

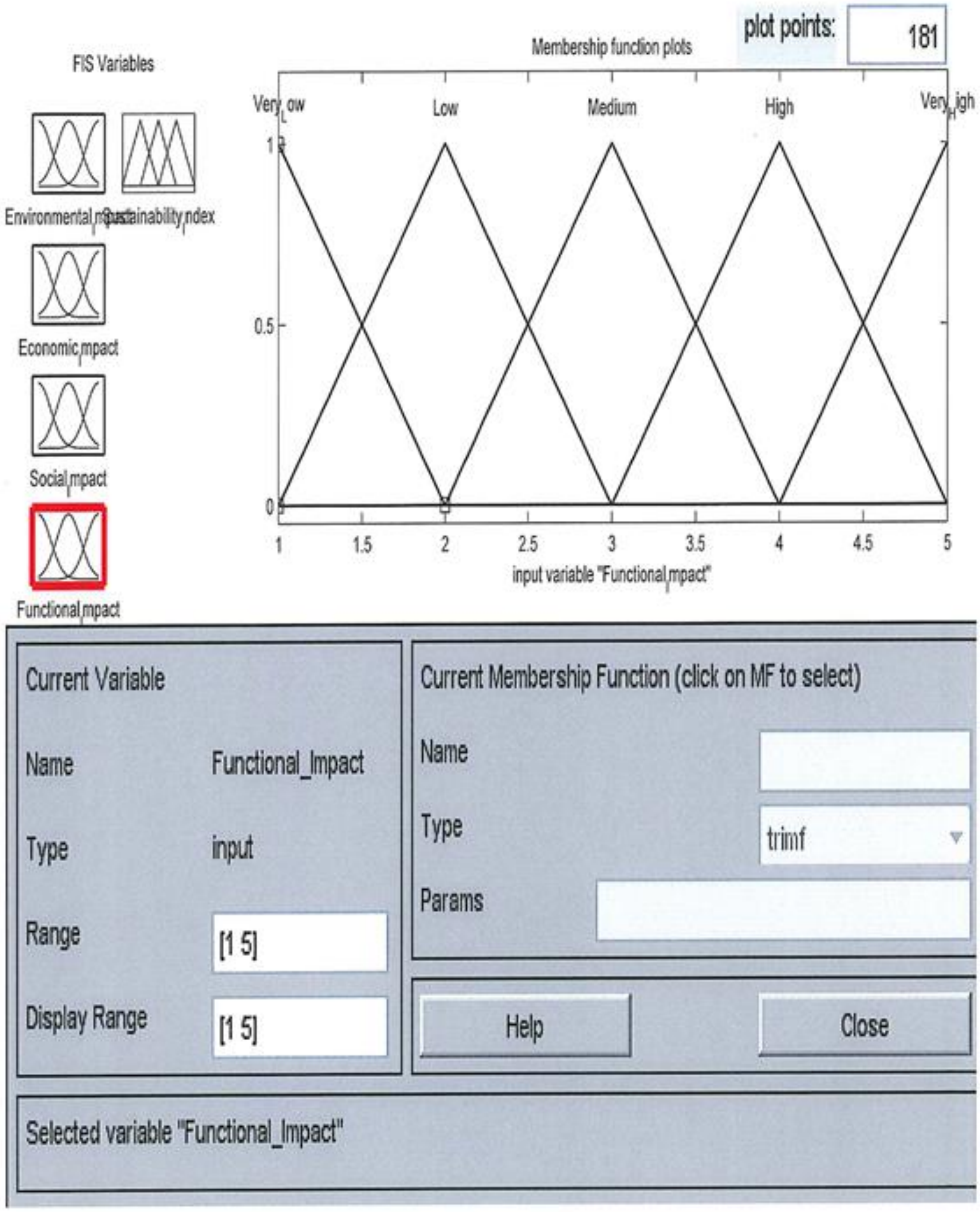


Figure 6.8: Membership functions of the input variable of functional Impact

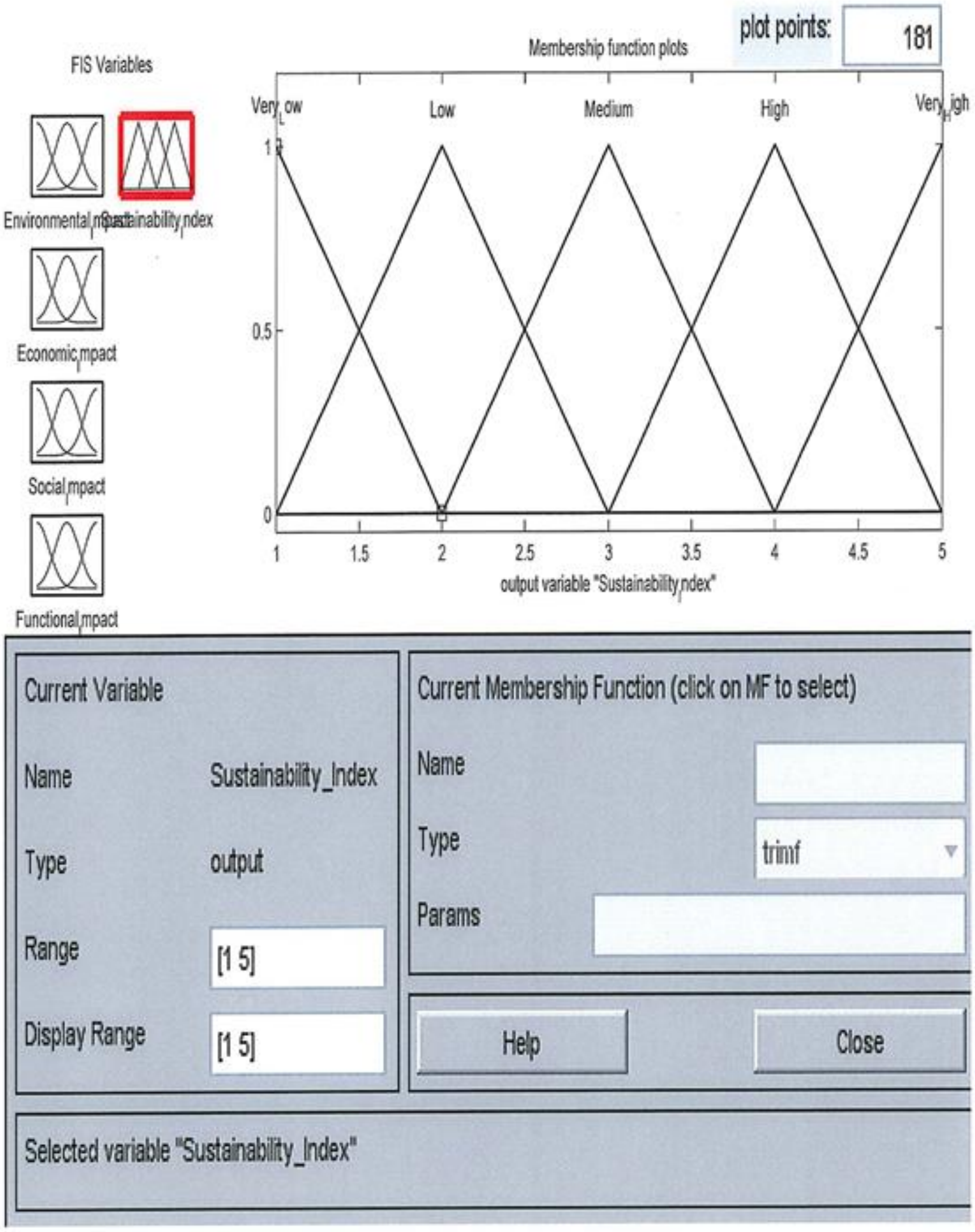


Figure 6.9: Membership functions of the output variable of sustainability index (Total Sustainability Impact)

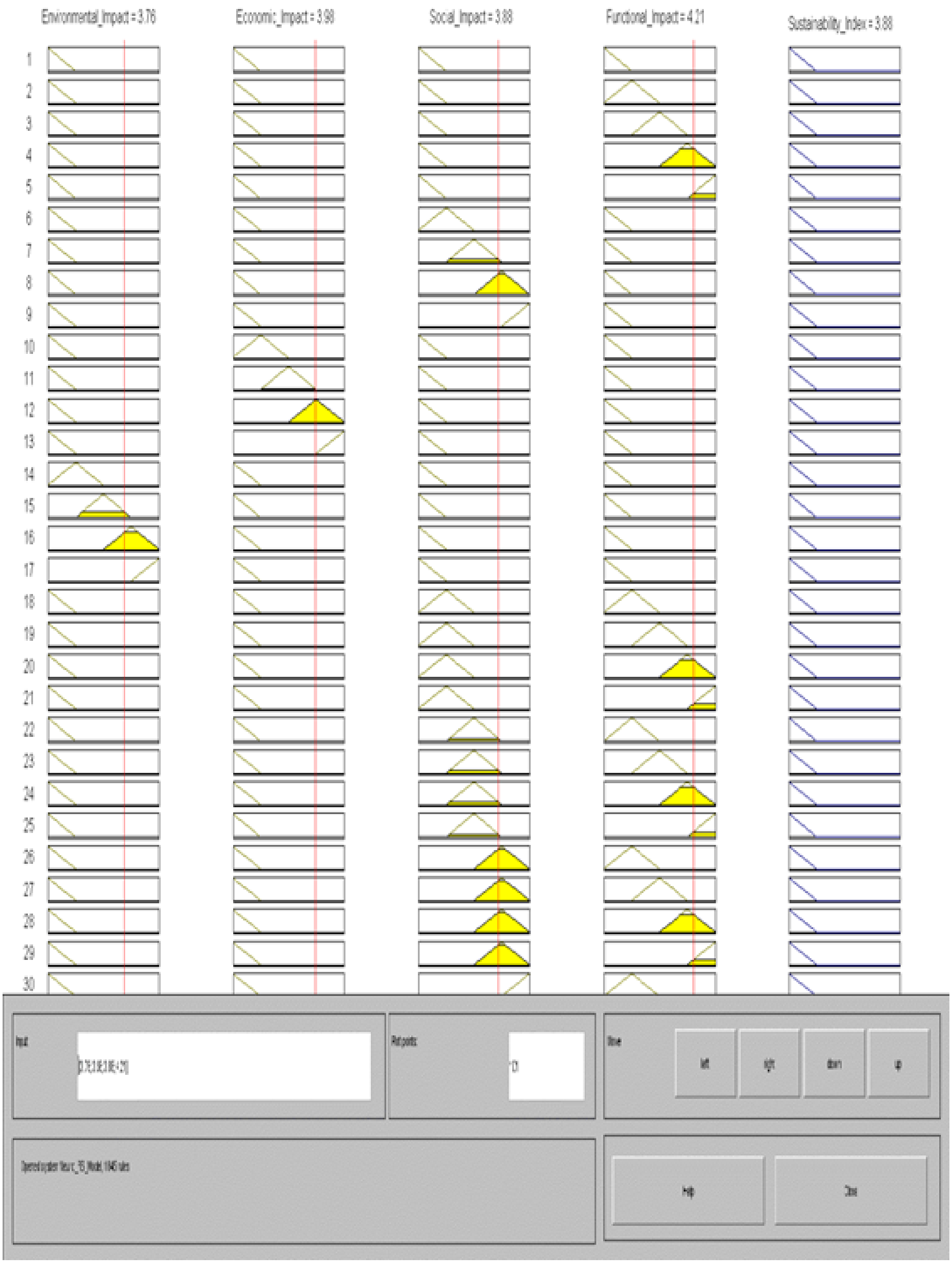


Figure 6.10:Output of the Neuro fuzzy model using the rule block

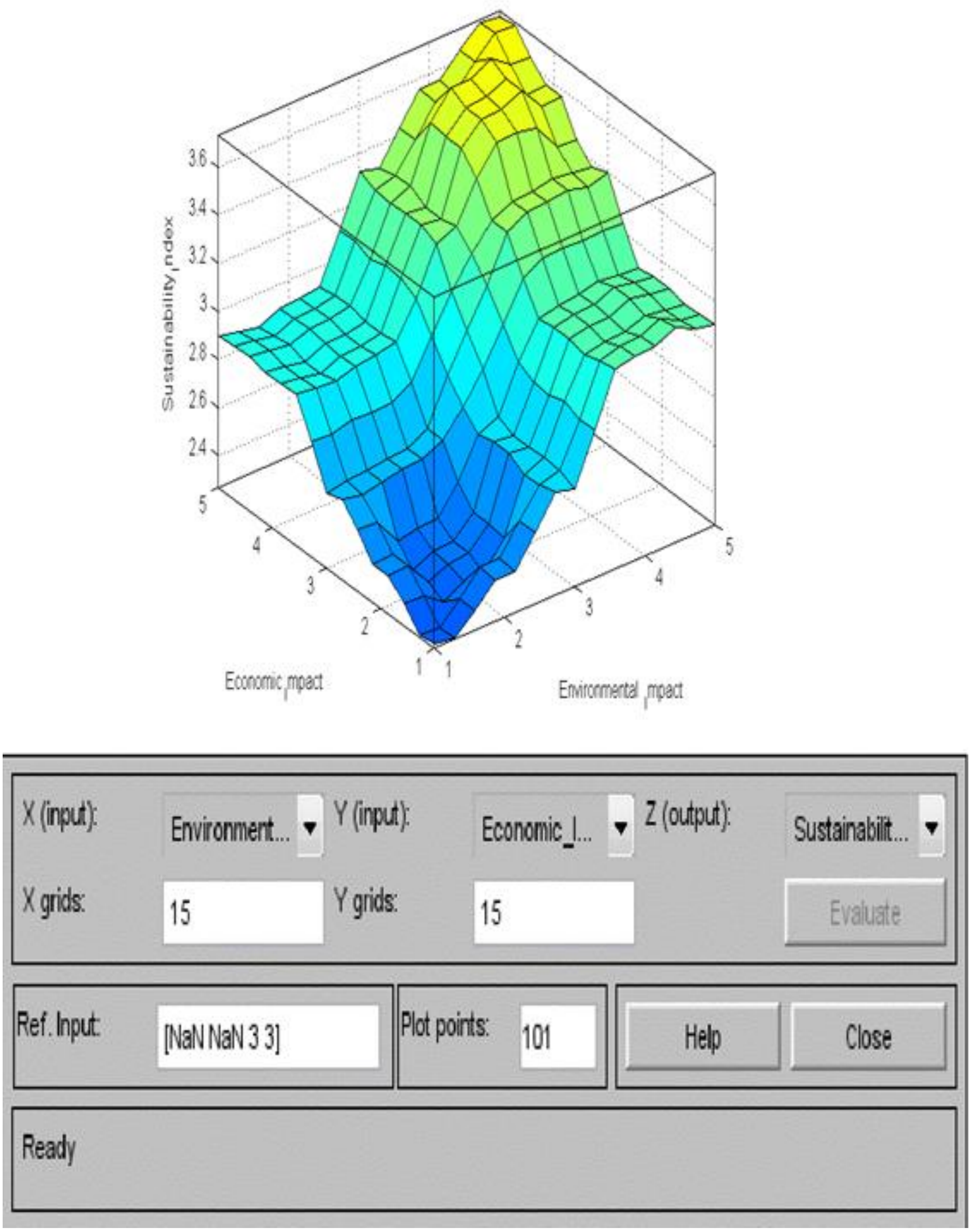


Figure 6.11:Surface view of the output

6.4 Concluding Remarks

Based on the developed decision-making hierarchical structure, the whole design was carried out to develop the decision-making model. According to the hierarchical structure, the evaluation process of the model followed two stages. Two analytical techniques, namely AHP and neuro-fuzzy systems, aided the evaluation process. The model was developed using two methods incorporating the analytical techniques. The first method only applied AHP for both evaluation stages. The second method applied AHP in the evaluation Stage 1 but a Neuro fuzzy system was the application for Stage 2. The model's output from either method delivers the total sustainability impact (sustainability index) of any given building component. Hence, the sustainability index indicates which building component is highly or less critical for the sustainable management of community buildings. Consequently, building components can be prioritised for their maintenance activities based on sustainability index values produced by the model.

7 VERIFICATION, VALIDATION AND DEMONSTRATION OF THE MODEL

7.1 Background

Simulation models are increasingly being used to solve problems and to aid in decision-making (Sargent, 2005). Such models are used to predict or compare the future performance of a new system, a modified system, or an existing system under new conditions (Carson, 2002). For models used for comparison purposes, Carson (2002) emphasizes that the comparison is usually made of a baseline model representing an existing system, with someone's conception of how a new or modified system will work (i.e. to a baseline design), or to current real-world system performance. The developers and users of these models, the decision-makers using information obtained from the results of these models, and the individuals affected by decisions based on such models are all rightly concerned with whether a model and its results are correct. This concern is addressed by model verification and validation.

In the context of computer simulation models, verification of a model is the process of confirming it is correctly implemented with respect to the conceptual model, that is, it matches specifications and assumptions deemed acceptable for the given purpose of application (Carson, 2002). During verification, the model is tested to find and correct errors in the implementation of the model (Carson, 2002), and this writer outlines various processes and techniques used to assure the model matches specifications and assumptions with respect to the model concept. At a minimum, the objective of model verification is to ensure that the implementation of the model is correct.

Validation checks the accuracy of the model's representation of the real system (Carson, 2002, Sargent, 2005). Model validation is defined as "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model"(Schlesinger et al., 1979) cited in (Sargent, 2005). A model should be built for a specific purpose or set of objectives and its validity determined for that purpose (Sargent, 2005).

7.2 Verification of the current model

Development of the current model followed a systematic process of expert verification. As the first step, the expert opinion of six partner councils was consulted to identify the aspects and their factors concerned with the sustainable management of community buildings. Their agreement was verified by a majority of local councils in Australia, based on an industry-wide questionnaire. Hence, any errors due to the parameters applied in the model are unlikely to have an impact on the final results of the model. The second phase of the model's implementation was in relation to the weightings of aspects and criteria of the model. Default values were assigned for those data based on another industrial-wide questionnaire. Hence, weighting values seldom produced any error in the final result of the model. The last phase of the model's implementation was assigning impact values of building components through sustainability criteria. The research proposed a qualitative and quantitative process to acquire the impact values which were only qualitative in nature. The process included linguistic impacts incorporated with numbers and followed by definitions, which minimises subjectivity to a degree. Hence, it has minimised the errors on the final result of the model due to impact data. All phases have taken sufficient precautionary steps to minimise the errors of the implementation. Hence, the current model is verified.

7.3 Validation of the current model

The output of the current model is the total sustainability impact caused by a building component. Since these values are not measurable in nature, the output is intangible. For that reason, there are no observable values to be compared with the model's outputs. Therefore, the operational validity of the model is not executable. In contrast, conceptual model validity is determined by two factors: (1) the theories and assumption underlying the conceptual model are correct and (2) the model's representation of the problem entity and the model's structure, logic and mathematical and causal relationships are “reasonable” for the intended purpose of the model (Sargent, 2005). Hence, the current model’s validity belongs to conceptual model validity, which requires checking of the credibility of theories applied in the evaluation process for the intended purpose. AHP and neuro-fuzzy system applications were involved in this purpose. Their past applications in decision-making problems have provided results with high credibility (see Sections 2.7 and 2.8). On the other hand, the model’s sole purpose was not to obtain the total sustainability impact, but to compare the values of different building components for prioritisation. Also, the following comment was made by the partner councils participating in the last workshop with the research team.

> *The model provides a systematic approach to measure the total sustainability impact caused by each building component through scores, which can be later utilized for the prioritisation purpose.*

Hence, a satisfactory range of accuracy is consistent with the intended application of the model. Therefore, the current model is validated.

7.4 Demonstration of the model

Under this section, the model is demonstrated using data in order to show how the model runs. The output results are shown according to the two models applied in this research. Hence, another aim of this section is to distinguish the two models based on the results. Two case studies were undertaken to demonstrate the model. The first case study was undertaken with a partner council of the research. The case followed the same element hierarchy as the council and the sheet of impact values was created against the element hierarchy. The researcher consulted the building manager who is involved in the management of community buildings to seek the impact values of all 18 criteria by the building components at their best condition and worst condition. In addition, the study used the default weighting values, which were found from industry-wide Questionnaire 2 (see Chapter 5). The study selected one of the council’s community halls for the case study and included its condition data.

The second case included 53 building components following the NAMS building hierarchy. The importing of impact data was hypothetical to a degree because at the time of the study, no partner council adopted the NAMS hierarchy in their system. However, some steps had already been taken for the transformation to NAMS in the future. The research team suggested and fed the impact values of 18 criteria for all the building components according to their best condition and worst condition. A similar method to that applied in Case 1 was used to assign the weighting values for all criteria, which were the default weighting values. The condition data were also assigned hypothetically.

7.4.1 Case study 1

The first step of the evaluation was to assign the default weighting values for each aspect and criteria. Those values were already captured and stated from Tables 5.21 to 5.25 in Chapter 5. The same codes for aspect and criteria are used in the tables here which are intended to gain impact values (codes are used to condense the impact data sheet otherwise it is extremely large). Table 7.1 shows the impact values and condition data pertinent to Case study 1. Note that m and n values of the table are the impact values of criteria related to the building components at their worst condition and best condition, respectively. For example, for the element “Cabinets” (under the main element group of “Essential Services”), condition is given as condition 2. Related to impact data, the impact by the element at its both worst and best condition based on the environmental factor En1 (Reduction of Green House Gas emission) is equivalent to 1, which is very low impact caused by the element. In another example, the element called “Mechanical & Air Conditioning” belonged to the same element group (“Essential Services”) at its best condition caused an impact of 3 (Medium and captured under the sub-column of “n”) through the economic factor Ec1, which is “Additional capital investment cost”. The same element caused an impact of 5 (Very low and captured under the sub-column of “m”) at its worst condition.

Using method 1 of the model in which only AHP was applied, the impact values on the environmental, economic, social and functional aspects were calculated. They are represented here as the environmental, economic, social and functional index of the building components, respectively. For example, the environmental index of the element “Cabinets” is calculated as follows. Based on the existing condition value and “n” and “m” values of all environmental factors, the impact caused by the element at its current condition is calculated from Equation 6.1 (e.g. For En1, the result is 1). Then all calculated values are applied in Equation 6.2 which will calculate the total environmental index of “Cabinets”, value of 1 as shown in Table 7.2. The same process can be applied to other aspects to calculate their index.

Finally, evaluation Stage 2 was performed using both methods (Method 1 and Method 2). For example using Method 1 for “Cabinets”, all index values previously obtained from Equation 6.2 (Environmental=1, Economic=1, Social=1.07 and Functional=2.72) are multiplied with their related weighting values according to Equation 6.3, which will give the total sustainability index value for “Cabinets”. In Method 2, all index values obtained from Equation 6.2 will be entered into the Neuro-fuzzy model, which will give the total sustainability index in its output. Likewise, all the results obtained from both models are shown in Table 7.2.

Table 7.1: Impact values for Case study 1

Element Group	Element	Condition	Impact																																											
			Environmental Criteria														Economic Criteria								Social Criteria								Functional Criteria					
			En 1		En 2		En 3		En 4		En 5		En 6		En 7		Ec 1		Ec 2		Ec 3		Ec 4		Sc 1		Sc 2		Sc 3		Sc 4		Fn 1		Fn 2		Fn 3	
			n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m
Essential Services	Cabinets	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Emergency Lights	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Exit Doors	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Exit Signs	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Fire Blanket	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Fire Hydrants/fire mains	3	1	5	1	1	1	1	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Fire detector alarm system	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Hose fittings & blanking caps	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Mechanical & Air Conditioning	3	1	5	1	1	1	5	1	1	1	5	1	1	1	1	3	5	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Paths of travel to exits	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Portable fire extinguishers	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5

	Smoke Doors/Fire Doors	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Smoke detectors	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Valves	3	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
Finishes	Floors	2	1	1	1	2	1	3	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Wall	2	1	1	1	2	1	3	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	kitchen	2	1	1	1	1	1	1	1	2	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
Fittings	Door Furniture	2	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Door closers	2	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Fitments	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	3	5	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	3	5	5	5
Services	ESM	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	5	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Electrical	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	5	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Fire	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	5	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	5	5	5
	Mechanical	3	1	5	1	1	1	5	1	1	1	1	1	5	1	1	3	5	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	3	5	5	5
	Plumbing	4	1	5	1	1	1	5	1	1	1	1	1	5	1	1	3	5	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	3	5	5	5
Substructure	Column	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Column foundations	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Damp-proofing membranes	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Entrance steps	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Foundation	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5

	Foundation walls	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Ground floor slab structures	3	1	1	1	2	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Ramps	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Strip footings	3	1	1	1	2	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Wooden stumps	3	1	1	1	2	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	stumps	3	1	1	1	2	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
Superstructure	Ceiling	2	1	1	1	2	1	3	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	External Doors	3	1	1	1	2	1	5	1	1	1	5	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	External Wall	3	1	1	1	3	1	5	1	1	1	5	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Internal Doors	2	1	1	1	2	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Internal Screens	4	1	1	1	1	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Internal Wall	2	1	1	1	2	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Roof	4	1	1	1	5	1	5	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Stairs	3	1	1	1	1	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Upper Floors	3	1	1	1	2	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Veranda post	2	1	1	1	1	1	1	1	1	1	1	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5
	Windows	4	1	1	1	5	1	1	1	1	1	5	1	5	1	1	2	3	1	1	1	1	1	1	1	5	1	1	1	3	1	5	1	1	1	1	5	5

Table 7.2: Sustainability index values for Case study 1

Element Group	Element	Environmental index	Economic index	Social index	Functional index	Sustainability index	
						Using the Model 1 (AHP)	Using the model 2 (Combined AHP and NFS)
Essential Services	Cabinets	1	1	1.07	2.72	1.31	1.95
	Emergency Lights	1	1	1.07	2.72	1.31	1.95
	Exit Doors	1	1	1.14	2.86	1.35	2.01
	Exit Signs	1	1	1.21	3	1.39	2.05
	Fire Blanket	1	1	1.14	2.86	1.35	2.01
	Fire Hydrants/fire mains	1.46	1.83	1.14	2.86	1.75	2.27
	Fire detector alarm system	1	1	1.14	2.86	1.35	2.01
	Hose fittings & blanking caps	1	1	1.14	2.86	1.35	2.01
	Mechanical & Air Conditioning	2.06	2.67	1.14	2.86	2.19	2.53
	Paths of travel to exits	1	1	1.07	2.72	1.31	1.95
	Portable fire extinguishers	1	1	1.14	2.86	1.35	2.01
	Smoke Doors/Fire Doors	1	1	1.14	2.86	1.35	2.01
	Smoke detectors	1	1	1.14	2.86	1.35	2.01
	Valves	1.46	1	1.14	2.86	1.52	2.17
Finishes	Floors	1.24	1	1.6	2.02	1.38	2.03
	Wall	1.24	1	1.6	2.02	1.38	2.03
	kitchen	1.11	1	1.6	2.02	1.33	1.98

Fittings	Door Furniture	1.08	1	1.6	2.02	1.32	1.98
	Door closers	1.08	1	1.6	2.02	1.32	1.98
	Fitments	1.16	2.67	2.2	2.86	2.06	2.51
Services	ESM	1	2.67	1.14	2.86	1.8	2.4
	Electrical	1	2.67	1.14	2.86	1.8	2.4
	Fire	1	2.67	1.14	2.86	1.8	2.4
	Mechanical	2.05	2.67	2.2	2.86	2.39	2.6
	Plumbing	2.57	2.95	2.8	3	2.79	2.77
Substructure	Column	1.16	1.83	2.2	2.02	1.69	2.25
	Column foundations	1.16	1	2.2	2.02	1.46	2.16
	Damp-proofing membranes	1.16	1	2.2	2.02	1.46	2.16
	Entrance steps	1.16	1	2.2	2.02	1.46	2.16
	Foundation	1.16	1	2.2	2.02	1.46	2.16
	Foundation walls	1.16	1	2.2	2.02	1.46	2.16
	Ground floor slab structures	1.26	1	2.2	2.02	1.5	2.16
	Ramps	1.16	1	2.2	2.02	1.46	2.16
	Strip footings	1.26	1	2.2	2.02	1.5	2.16
	Wooden stumps	1.26	1	2.2	2.02	1.5	2.16
	stumps	1.26	1.83	2.2	2.02	1.72	2.25
Superstructure	Ceiling	1.24	1.7	1.6	2.02	1.57	2.2
	External Doors	1.86	1.83	2.2	2.02	1.94	2.43
	External Wall	1.97	1.83	2.2	2.02	1.98	2.45
	Internal Doors	1.13	1.7	1.6	2.02	1.53	2.17
	Internal Screens	1.24	1.97	2.8	2.02	1.86	2.41

	Internal Wall	1.13	1.7	1.6	2.02	1.53	2.17
	Roof	2.52	1.97	2.8	2.02	2.34	2.58
	Stairs	1.16	1.83	2.2	2.02	1.69	2.25
	Upper Floors	1.26	1.83	2.2	2.02	1.72	2.25
	Veranda post	1.08	1.7	1.6	2.02	1.51	2.17
	Windows	2.12	1.97	2.8	2.02	2.19	2.53

7.4.2 Case study 2

A similar procedure was adopted for case study 2. Default weightings were assigned for aspects and criteria. Following the format of Table 7.1, Table 7.3 shows impact values and condition data for the building components of case study 2. According to the weighting values, condition data and impact values, outputs are produced by two models. The outputs belong to the values of the environmental index, economic index, social index, functional index and sustainability index of the building components. Table 7.4 provides all the results generated by both models.

Table 7.3: Impact values for Case study 2

Component Group	Component Type	Component	Condition	Impact																																			
				Environmental Criteria														Economic Criteria								Social Criteria								Functional Criteria					
				En 1		En 2		En 3		En 4		En 5		En 6		En 7		Ec 1		Ec 2		Ec 3		Ec 4		Sc 1		Sc 2		Sc 3		Sc 4		Fn 1		Fn 2		Fn 3	
				n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m
Electrical Services	**Distribution Boards**	Main Switch Board	3	1	1	3	4	1	2	1	1	1	1	1	1	1	1	3	4	1	1	1	1	1	1	2	5	1	5	1	1	2	5	5	5	1	3	1	4
	Emergency Lighting (Not fire related)	Controller / Cabling	4	1	1	3	4	1	2	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	4	1	5	1	2	1	2	5	5	1	3	1	5
	Emergency Power	Gen Set - engine	2	1	1	2	3	5	5	1	1	3	4	2	4	1	1	4	5	3	3	1	1	1	1	1	4	1	5	1	1	2	4	5	5	1	3	1	4
	Lighting - External/Internal	Down Lights	3	1	1	3	4	3	4	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	5	1	5	1	4	1	2	3	4	1	3	1	3
	Lighting - Flood / Security	Pole Top Lights (External)	3	1	1	3	4	4	5	1	1	1	1	1	1	1	1	3	4	1	1	1	1	1	1	1	5	1	5	1	4	1	3	5	5	1	3	1	4
	Misc.	Light Switches & Powerpoints	2	1	1	4	5	1	2	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	5	1	5	1	2	1	4	4	5	1	3	1	4
	Power Conditioning	Chargers	1	1	1	3	4	3	4	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	3	1	5	1	1	1	2	4	5	1	3	1	4
	Power Conversion	Power conversion	1	1	1	3	4	2	3	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	3	1	5	1	1	1	2	4	5	1	3	1	3
Exterior Works	**Buildings**	Covered Ways	2	1	1	3	4	1	1	3	3	1	1	1	1	1	1	3	4	3	3	1	1	1	1	1	3	1	1	1	3	1	2	3	4	1	3	1	4
	Channels	Channels &	2	1	1	2	3	1	1	4	4	1	1	1	1	1	1	3	4	4	4	1	1	1	1	1	3	1	4	1	2	1	2	3	4	1	3	1	2

		Grating																																					
	Civil works	Retaining Walls (Concrete)	2	1	1	2	3	1	1	3	3	1	1	1	1	1	1	3	5	5	5	1	1	1	1	1	2	1	1	1	2	1	2	4	5	1	3	1	4
	Fencing	Corrugated Iron Fence	3	1	1	3	4	1	1	3	3	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	2	1	3	1	2	1	2	3	4	1	3	1	2
	Furniture	Park Seat	4	1	1	3	4	1	1	3	3	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	5	1	4	1	3	1	2	3	4	1	3	1	3
	Gates	Metal Gate	5	1	1	3	4	1	1	2	2	1	1	1	1	1	1	3	4	3	3	1	1	1	1	1	2	1	3	1	3	1	2	4	5	1	3	1	3
	Hard stand	Asphalt /Sealed Areas	4	1	1	3	4	1	1	3	3	1	1	1	1	1	1	3	5	4	4	1	1	1	1	1	3	1	3	1	4	1	2	3	4	1	3	1	3
	Misc.	Decking	4	1	1	3	4	1	1	3	3	1	1	1	1	1	1	3	4	3	3	1	1	1	1	1	2	1	3	1	3	1	2	3	4	1	3	1	3
	Signs	Sign (Route)	2	1	1	3	4	2	3	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	3	1	2	1	5	1	2	4	5	1	3	1	2
	Stairs & rails	Staircase - Metal	3	1	1	3	4	1	1	2	2	1	1	1	1	1	1	3	4	3	3	1	1	1	5	1	4	1	4	1	3	1	2	4	5	1	3	1	4
	Water tanks	Water Tank - Plastic	4	5	5	3	4	1	1	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	1	1	2	1	2	5	5	1	3	1	4
External Fabric	**External Walls**	Brick Cladding	2	1	1	3	4	1	1	3	3	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	2	1	1	1	4	1	2	3	4	1	3	1	1
	Roof	Downpipes - Metal	5	4	5	3	4	1	1	3	3	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	2	1	1	1	2	1	2	3	4	1	3	1	1
	Windows & Doors	Alum Frame Glass - Dble Door	1	1	1	3	4	1	1	2	2	1	1	1	1	1	1	1	3	3	3	1	1	1	1	1	3	1	1	1	4	1	2	4	5	1	3	1	2

Fire Services	**Fire Alarm System**	Smoke detectors	2	1	1	4	5	1	2	2	2	3	3	1	1	1	1	1	2	3	3	1	1	1	1	1	3	1	4	1	3	1	2	5	5	1	3	1	5
	Fire Communications	EWIS panel	2	1	1	3	4	2	3	2	2	3	3	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	3	1	2	3	4	1	3	1	4
	Fire Sprinkler System	Pipes and valves	3	5	5	3	4	1	1	2	2	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	3	1	4	1	1	1	2	4	5	1	3	1	2
	Hydrant System	Hydrant System	3	5	5	3	4	3	4	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	3	1	2	3	4	1	3	1	5
Interior Finishes	**Ceiling Finishes**	Insulation	4	1	1	3	4	1	1	2	2	1	1	1	4	1	1	2	4	3	3	1	1	1	1	1	2	1	1	1	1	1	2	4	5	1	3	1	4
	Fixtures & Fittings	Kitchen Bench S/S	2	1	1	3	4	1	1	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	4	1	3	1	3	1	2	5	5	1	3	1	4
	Floor Finishes	Epoxy	3	1	1	3	4	1	1	3	3	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	4	1	2	1	4	1	2	3	4	1	3	1	3
	Interior Doors	Fire Doors	2	1	1	2	3	1	1	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	1	1	2	1	2	5	5	1	3	1	5
	Interior Walls	Int Window - Metal	3	1	1	3	4	1	1	2	2	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	3	1	1	1	3	1	2	3	3	1	3	1	3
	Interior Windows	Alum/ Safety glass	1	1	1	3	4	1	1	2	2	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	3	1	1	1	4	1	2	5	5	1	3	1	5
	Wall Finishes	Plaster Finish	5	1	1	3	4	1	1	2	2	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	3	1	1	1	4	1	2	4	5	1	3	1	1

Lifts / Hoist Services	**Vertical Transport**	Motor / Gears	4	1	1	3	4	5	5	1	1	1	4	1	1	1	1	3	5	3	3	1	1	1	1	1	4	1	5	1	1	1	2	4	5	1	3	1	2
Mechanical Services	**Air Distribution**	Ducting	3	1	1	2	3	1	1	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	1	1	2	3	4	1	3	1	3
	Air Handling Units	AHU - Motor	2	1	1	3	4	4	5	2	2	3	5	1	5	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	1	1	2	3	4	1	3	1	3
	Building Management System	Cabling / mech / elect	3	1	1	2	3	1	2	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	4	1	4	1	1	1	2	3	4	1	3	1	1
	Chilled Water System	Chiller - Compressor	2	5	5	2	3	4	5	2	2	3	5	1	1	1	1	2	5	3	3	1	1	1	1	1	5	1	4	1	1	1	2	3	4	1	3	1	3
	Compressed Air/Pneumatics	Controller / Cabling	3	1	1	2	3	1	2	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	1	1	2	3	4	1	3	1	2
	Condenser Water System	Condensing Unit	4	5	5	2	3	3	4	2	2	2	3	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	1	1	2	4	5	1	3	1	3
	Fan Coil Units	Fan Coil Unit	2	1	1	3	4	3	4	2	2	3	4	1	4	1	1	2	3	3	3	1	1	1	1	1	3	1	4	1	1	1	2	4	5	1	3	1	4
	Heating System	Boiler - gas fired	3	5	5	3	4	3	4	2	2	3	4	3	5	1	1	2	4	3	3	1	1	1	1	1	5	1	4	1	2	1	2	4	5	1	3	1	4
	HVAC Control System	HVAC Control System	2	2	3	2	3	5	5	2	2	2	4	1	5	1	1	3	5	4	4	1	1	1	1	1	5	1	4	1	3	1	2	3	4	1	3	1	4
	Split A/C Units	Split A/C Units	3	2	3	3	4	4	5	2	2	1	3	1	5	1	1	3	5	3	3	1	1	1	1	1	5	1	4	1	3	1	2	4	5	1	3	1	4
	Ventilation System	Centrifugal Ventilation Fans	3	1	1	3	4	3	4	2	2	2	4	1	5	1	1	2	4	3	3	1	1	1	1	1	5	1	4	1	3	1	2	3	4	1	3	1	3

Plumbing	**Sanitary Plumbing**	Toilet Bowl & Cistern	4	5	5	3	4	1	1	2	2	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	5	1	4	1	3	1	2	4	5	1	3	1	1
Security Services	**Access Control Systems**	Card readers / Keypad	2	1	1	3	4	2	3	2	2	1	1	1	1	1	1	2	3	3	3	1	1	1	1	1	1	1	1	1	3	1	2	4	5	1	3	1	3
	CCTV Systems	Monitors	3	1	1	3	4	3	4	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	4	1	4	1	3	1	2	4	5	1	3	1	4
	Intruder/Duress Alarm System	Sensors	3	1	1	3	4	3	4	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	3	1	2	4	5	1	3	1	4
	Special Services	Barrier Arms	1	1	1	3	4	2	3	2	2	1	2	1	1	1	1	2	3	3	3	1	1	1	1	1	3	1	1	1	4	1	2	5	5	1	3	1	4
Water services	**Domestic Cold Water**	Tanks-Pipes	3	5	5	3	4	1	1	2	2	1	1	1	1	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	1	1	2	2	3	1	3	1	3
	Domestic Hot Water	Circulation Pumps	2	5	5	3	4	3	4	2	2	3	4	2	3	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	1	1	2	3	4	1	3	1	5
	Warm Water	Pumps	3	5	5	3	4	3	4	2	2	3	4	2	3	1	1	2	4	3	3	1	1	1	1	1	3	1	4	1	2	1	2	3	4	1	3	1	3

Table 7.4: Sustainability index values for Case study 2

Component Group	Component Type	Component	Environmental index	Economic index	Social index	Functional index	Sustainability index	
							Using the Model 1	Using the Model 2
Electrical Services	**Distribution Boards**	Main Switch Board	1.64	2.39	2.98	3.53	2.42	2.93
	Emergency Lighting (Not fire related)	Controller / Cabling	1.74	1.97	3.12	4.05	2.46	2.81
	Emergency Power	Gen Set - engine	2.43	3.05	1.81	3.19	2.62	2.65
	Lighting - External/Internal	Down Lights	2.06	1.83	2.77	2.7	2.24	2.65
	Lighting - Flood / Security	Pole Top Lights (External)	2.28	2.39	2.82	3.53	2.63	2.6
	Misc.	Light Switches & Power points	1.74	1.7	1.87	2.85	1.94	2.58
	Power Conditioning	Chargers	1.85	1.56	1	2.4	1.71	2.55
	Power Conversion	Power conversion	1.64	1.56	1	2.4	1.63	2.53
Exterior Works	**Buildings**	Covered Ways	1.71	2.49	1.31	2.38	1.97	2.49
	Channels	Channels & Grating	1.62	2.62	1.52	2.25	1.98	2.47
	Civil works	Retaining Walls (Concrete)	1.5	2.88	1.17	2.85	2.05	2.45
	Fencing	Corrugated Iron Fence	1.76	2.36	1.66	2.57	2.05	2.42
	Furniture	Park Seat	1.82	2.22	3.3	3.08	2.42	2.4
	Gates	Metal Gate	1.75	2.91	2.47	3.93	2.58	2.39

	Hard stand	Asphalt /Sealed Areas	1.82	3.31	2.53	3.08	2.57	2.36
	Misc.	Decking	1.82	2.77	2.1	3.08	2.35	2.35
	Signs	Sign (Route)	1.74	1.14	1.46	2.72	1.7	2.32
	Stairs & rails	Staircase - Metal	1.65	2.94	2.32	3.29	2.41	2.31
	Water tanks	Water Tank - Plastic	1.7	2.63	1.82	3.86	2.35	2.3
External Fabric	**External Walls**	Brick Cladding	1.71	2.08	1.24	2.19	1.81	2.28
	Roof	Downpipes - Metal	1.87	2.91	1.67	2.95	2.31	2.25
	Windows & Doors	Alum Frame Glass - Dble Door	1.54	1.24	1	2.4	1.51	2.24
Fire Services	**Fire Alarm System**	Smoke detectors	2.02	1.38	1.55	3.26	1.98	2.22
	Fire Communications	EWIS panel	2.03	2.08	1.55	2.38	2.02	2.2
	Fire Sprinkler System	Pipes and valves	1.65	2.08	1.97	3.04	2.07	2.18
	Hydrant System	Hydrant System	2.18	2.36	2.11	2.95	2.35	2.17
Fi	**Ceiling Finishes**	Insulation	1.88	2.63	1.4	3.74	2.32	2.16

	Fixtures & Fittings	Kitchen Bench S/S	1.59	2.08	1.58	3.19	2	2.15
	Floor Finishes	Epoxy	1.76	2.36	2.06	2.7	2.14	2.12
	Interior Doors	Fire Doors	1.38	2.08	1.27	3.26	1.88	2.1
	Interior Walls	Int Window - Metal	1.65	2.08	1.62	2.47	1.9	2.09
	Interior Windows	Alum/ Safety glass	1.54	1.8	1	2.86	1.74	2.07
	Wall Finishes	Plaster Finish	1.75	2.36	2.38	3.42	2.32	2.05
Lifts / Hoist Services	**Vertical Transport**	Motor / Gears	2.63	3.19	3.01	3.36	2.98	2.04
Mechanical Services	**Air Distribution**	Ducting	1.43	2.36	1.97	2.7	2	2.02
	Air Handling Units	AHU - Motor	2.58	2.08	1.48	2.32	2.19	2
	Building Management System	Cabling / mech / elect	1.54	2.36	2.18	2.44	2.04	1.99
	Chilled Water System	Chiller - Compressor	2.29	2.22	1.69	2.32	2.16	1.98
	Compressed Air/Pneumatics	Controller / Cabling	1.54	2.36	1.97	2.57	2.02	1.97
	Condenser Water System	Condensing Unit	2.22	2.63	2.45	3.55	2.61	1.95
	Fan Coil Units	Fan Coil Unit	2.32	1.94	1.48	2.85	2.15	1.94
	Heating System	Boiler - gas fired	2.63	2.36	2.46	3.29	2.64	1.92

	HVAC Control System	HVAC Control System	2.44	2.75	1.77	2.38	2.39	1.91
	Split A/C Units	Split A/C Units	2.64	2.91	2.53	3.29	2.81	1.88
	Ventilation System	Centrifugal Ventilation Fans	2.51	2.36	2.53	2.7	2.5	1.86
Plumbing	**Sanitary Plumbing**	Toilet Bowl & Cistern	1.7	2.22	3.3	3.16	2.39	1.85
Security Services	**Access Control Systems**	Card readers / Keypad	1.86	1.94	1.1	2.78	1.9	1.83
	CCTV Systems	Monitors	2.18	2.36	2.32	3.29	2.45	1.81
	Intruder/Duress Alarm System	Sensors	2.18	2.36	2.11	3.29	2.41	1.8
	Special Services	Barrier Arms	1.75	1.8	1	2.86	1.82	1.78
Water services	**Domestic Cold Water**	Tanks- Pipes	1.65	2.36	1.97	2.23	2	1.76
	Domestic Hot Water	Circulation Pumps	2.36	2.08	1.48	2.44	2.14	1.72
	Warm Water	Pumps	2.51	2.36	2.04	2.7	2.41	1.7

7.5 Concluding remarks

In this chapter, verification, validation and demonstration of the model have been discussed. Possible errors during the implementation of the model were considered for the verification of the model. The model's validation belongs to conceptual model validity, and the model was validated accordingly. The demonstration of the model was done with the aid of data from two case studies. The main output of both models was the sustainability index value. Together with main output results for both models, separate index results for each sustainability aspect (Environmental index, Economic index, Social index and Functional index) were demonstrated. Different sustainability index values were found for the two models but their ranking values were very similar (see Chapter 8).

8 INTEGRATED DECISION-MAKING

8.1 Introduction

This chapter addresses three aspects which are highly important in the sustainable management of community buildings. It has been called integrated decision-making because two or more attributes are required for making the decision. The three aspects are:

1. Prioritising maintenance activities of building components based on sustainability impact values
2. Optimising cost in maintenance activities under ongoing deterioration
3. Determining the best intervention times of whole building assets for their renewals during the planned period

Most local councils struggle to prioritise maintenance actions within limited budget allocation annually or a planned period. The majority only considers the cost value spent for the maintenance in their prioritisation process. However, very few adopt a better procedure comparing few aspects and criteria against the prioritisation of maintenance actions. Although it is theoretically sound, it has no objective way to implement the procedure rather than subjective decisions. It also found that the selected aspects and criteria are not sufficient for a comprehensive sustainable strategy. To overcome this problem, current research developed a decision-making model on the basis of comprehensive structure. The model provides sustainability index of building components as its outputs. Sustainability index values are compared and the components with higher index values are retained in the higher priority list for maintenance actions.

The second aspect is considered after the decision was made on the first aspect. This will provide an accurate estimate of maintenance actions if the component is planned to maintain on a particular condition during the plan. The program can be used two ways depending on the situation to be addressed. In one situation, minimum condition to be maintained during the planned period can be fixed and estimation is provided for maintenance actions for the period by the program. Another situation, the budget estimation is fixed so the program has to derive the maximum condition which can be maintained during the plan. The third aspect is important in making decisions for renewals during the planned period. This will provide time intervals best suited for the task hence; individual maintenance costs can be cut down until the major renewal happened.

8.2 Prioritising maintenance activities of building components based on the sustainability impact values

Chapter 7 illustrated the calculation of the sustainability index values of building components using data from two case studies. According to the results, several indices (environmental, economic, social and functional) are presented in addition to the sustainability index of the building components. Councils have the freedom to choose either index according to their preference to rank the criticality of the building components. For example, they can use sustainability index values for this purpose and rank 1 the building component with the highest sustainability index. Then the ranking continues with descending sustainability index values. Moreover, the building component with the least sustainability index receives the rank of 47 in general for the first case whereas it is the 53rd rank of the second case. As emphasized above, other index criteria (e.g. the environmental index) can also be used to rank the building components on criticality. Based on the rank, the building component entitled to rank 1 is given the highest priority for maintenance, whereas the least priority is given to the building component with the highest rank. Table 8.1 shows the different rankings depending on different index values for case 1. Table 8.2 does the similar task for case 2. When similar rankings are found for several building components, as in these tables, the cost of the maintenance action is compared against the building components for further ranking.

Table 8.1: Priority ranking of the building components according to case 1

Element Group	Element	Rank on					
		Environmental index	Economic index	Social index	Functional index	Sustainability index	
						Using the Model 1	Using the Model 2
Essential Services	Cabinets	34	22	22	45	45	45
	Emergency Lights	34	22	22	45	45	45
	Exit Doors	34	22	22	32	35	35
	Exit Signs	34	22	22	31	32	32
	Fire Blanket	34	22	22	32	35	35
	Fire Hydrants/fire mains	8	11	11	32	13	13
	Fire detector alarm system	34	22	22	32	35	35
	Hose fittings & blanking caps	34	22	22	32	35	35
	Mechanical & Air Conditioning	4	2	2	32	4	4
	Paths of travel to exits	34	22	22	45	45	45
	Portable fire extinguishers	34	22	22	32	35	35
	Smoke Doors/Fire Doors	34	22	22	32	35	35
	Smoke detectors	34	22	22	32	35	35
	Valves	8	22	22	32	21	19
Finishes	Floors	15	22	22	22	33	33
	Wall	15	22	22	22	33	33
	kitchen	30	22	22	22	42	42
Fittings	Door Furniture	31	22	22	22	43	42
	Door closers	31	22	22	22	43	42
	Fitments	19	2	2	5	6	6

Services	ESM	34	2	2	32	10	10
	Electrical	34	2	2	32	10	10
	Fire	34	2	2	32	10	10
	Mechanical	5	2	2	5	2	2
	Plumbing	1	1	1	1	1	1
Substructure	Column	19	11	11	5	16	14
	Column foundations	19	22	22	5	26	23
	Damp-proofing membranes	19	22	22	5	26	23
	Entrance steps	19	22	22	5	26	23
	Foundation	19	22	22	5	26	23
	Foundation walls	19	22	22	5	26	23
	Ground floor slab structures	10	22	22	5	23	23
	Ramps	19	22	22	5	26	23
	Strip footings	10	22	22	5	23	23
	Wooden stumps	10	22	22	5	23	23
	stumps	10	11	11	5	14	14
Superstructure	Ceiling	15	18	18	22	18	18
	External Doors	7	11	11	5	8	8
	External Wall	6	11	11	5	7	7
	Internal Doors	28	18	18	22	19	19
	Internal Screens	15	8	8	1	9	9
	Internal Wall	28	18	18	22	19	19
	Roof	2	8	8	1	3	3
	Stairs	19	11	11	5	16	14
	Upper Floors	10	11	11	5	14	14
	Veranda post	31	18	18	22	22	19
	Windows	3	8	8	1	4	4

Table 8.2: Priority ranking of the building components according to case 2

Component Group	Component Type	Component	Rank on: Environmental index	Economic index	Social index	Functional index	Sustainability index: Using the Model 1	Using the Model 2
Electrical Services	Distribution Boards	Main Switch Board	43	16	16	5	12	12
	Emergency Lighting (Not fire related)	Controller / Cabling	32	42	42	3	10	10
	Emergency Power	Gen Set - engine	8	3	3	29	5	5
	Lighting - External/Internal	Down Lights	17	45	45	7	25	25
	Lighting - Flood / Security	Pole Top Lights (External)	12	16	16	6	4	3
	Misc.	Light Switches & Power points	32	48	48	27	43	43
	Power Conditioning	Chargers	23	49	49	49	50	50
	Power Conversion	Power conversion	43	49	49	49	52	52
Exterior Works	Buildings	Covered Ways	35	15	15	44	42	42
	Channels	Channels & Grating	45	14	14	38	40	40
	Civil works	Retaining Walls (Concrete)	51	8	8	47	32	32
	Fencing	Corrugated Iron Fence	27	18	16	33	32	33
	Furniture	Park Seat	24	31	31	1	12	13
	Gates	Metal Gate	29	5	5	11	7	7
	Hard stand	Asphalt /Sealed Areas	24	1	1	8	8	8
	Misc.	Decking	24	9	9	20	19	19
	Signs	Sign (Route)	32	53	53	42	51	51
	Stairs & rails	Staircase - Metal	39	4	4	15	14	14
	Water tanks	Water Tank - Plastic	37	11	11	28	19	20
External Fabric	External Walls	Brick Cladding	35	34	34	46	48	48
	Roof	Downpipes - Metal	21	5	5	32	24	24
	Windows & Doors	Alum Frame Glass - Dble Door	47	52	52	49	53	53
Fire Services	Fire Alarm System	Smoke detectors	19	51	51	36	40	41
	Fire Communications	EWIS panel	18	34	34	36	35	35
	Fire Sprinkler System	Pipes and valves	39	34	34	23	31	31
	Hydrant System	Hydrant System	14	18	16	18	19	21

Indoor Finishes	Ceiling Finishes	Insulation	20	11	11	43	22	22
	Fixtures & Fittings	Kitchen Bench S/S	46	34	34	35	37	37
	Floor Finishes	Epoxy	27	18	16	21	29	29
	Interior Doors	Fire Doors	53	34	34	45	46	46
	Interior Walls	Int Window - Metal	39	34	34	34	44	44
	Interior Windows	Alum/ Safety glass	47	46	46	49	49	49
	Wall Finishes	Plaster Finish	29	18	16	14	22	23
Lifts / Hoist Services	Vertical Transport	Motor / Gears	2	2	2	4	1	1
Mechanical Services	Air Distribution	Ducting	52	18	16	23	37	38
	Air Handling Units	AHU - Motor	4	34	34	39	26	26
	Building Management System	Cabling / mech / elect	47	18	16	17	34	34
	Chilled Water System	Chiller - Compressor	11	31	31	31	27	27
	Compressed Air/Pneumatics	Controller / Cabling	47	18	16	23	35	36
	Condenser Water System	Condensing Unit	13	11	11	13	6	6
	Fan Coil Units	Fan Coil Unit	10	43	43	39	28	28
	Heating System	Boiler - gas fired	2	18	16	12	3	3
	HVAC Control System	HVAC Control System	7	10	10	30	17	17
	Split A/C Units	Split A/C Units	1	5	5	8	2	2
	Ventilation System	Centrifugal Ventilation Fans	5	18	16	8	9	9
Plumbing	Sanitary Plumbing	Toilet Bowl & Cistern	37	31	31	1	17	18
Security Services	Access Control Systems	Card readers / Keypad	22	43	43	48	44	45
	CCTV Systems	Monitors	14	18	16	15	11	11
	Intruder/Duress Alarm System	Sensors	14	18	16	18	14	15
	Special Services	Barrier Arms	29	46	46	49	47	47
Water services	Domestic Cold Water	Tanks- Pipes	39	18	16	23	37	39
	Domestic Hot Water	Circulation Pumps	9	34	34	39	29	30
	Warm Water	Pumps	5	18	16	22	14	16

8.3 Optimising cost in maintenance activities under ongoing deterioration

8.3.1 Background

Once building components are prioritised on sustainability, as in the previous section, the next task is to allocate costs for their maintenance. This is restricted by numerous factors, including:

- total cost allocated for a planned period
- minimum performance condition to be maintained for a given building component according to the minimum level of service
- ongoing deterioration

Cost optimisation here refers to the allocation of the planned budget on maintenance of building components to generate effective performance of the system and minimise backlog maintenance. The approach enables the calculation of cost values required for each building component to be maintained at any condition above the worst condition (condition 5). These values are a clear demonstration for an asset planner of allocation of the cost to each building component based on their required minimum performance. In reality, the budget may not be sufficient to achieve the required minimum performance. Therefore, the strategy achieving at least the required performance level of most critical building components leads to effective maintenance. The strategy can be extended by requiring a lower level of minimum performance for less critical building components to minimise backlog maintenance. Hence, the final solution depends on the user's purpose.

The Handbook of Rawlinson's construction cost guide provides cost values for four distinctive refurbishment actions for different building components (Rawlinsons, 2010). They are "Minor refurbishment cost", "Medium refurbishment cost", "Major refurbishment cost" and "Regeneration cost".

Moreover, actions can be interpreted as different condition upgrading, according to the ambition connected with each action. Accordingly, the minor refurbishment cost of a building component is the conversion cost required from condition 2 to 1. Following the same concept, costs related to actions from medium refurbishment to regeneration of a given building component mean conversion costs from condition 3 to 1, condition 4 to 1 and condition 5 to 1 respectively.

Deterioration is the main factor which causes maintenance actions for building components. Deterioration and the available methods for predicting it were discussed in Chapter 2. As previously stated, a parallel research was undertaken for that aspect (Mohseni, 2012). Hence, a Markov process-based probabilistic method (Mohseni et al., 2012a) was adopted in order to find the future condition proportions for cost optimisation. In fact, the basic results of the prediction model were percentage changes of each condition after one year according to a transition probability matrix.

8.3.2 Clarification using a hypothetical example

Let the current condition percentages of a given building component be the values represented in Table 8.1. Similarly, the conversion cost values related to conditions are represented by the values in Table 8.2. Those values assume that the whole building component is comprised of 100% of the lower condition requiring conversion, so that the conversion makes the building component be at 100% of condition 1. Hence, if there any percentage of that lower condition is converted to condition 1; the required cost can be calculated by the multiplication of the percentage and related conversion cost. For example, if the conversion cost of condition 2 to 1 is $4500 and 20% of condition 2 is required to be converted to 1, and then the result will be the cost amount of $900, which comes from the multiplication of 4500 and 20%. On the other hand, Figure 8.1 shows the transition probability matrix of the given building component provided that the transition happens every year. It is assumed that the council's planned period for maintenance actions is 10 years.

Table 8.3: Current condition percentages of the given building component

Condition	Percentage (%)
1	15
2	25
3	30
4	20
5	10

Table 8.4: Conversion costs of the given building component

Conversion of conditions	Cost ($)
2 to 1	4500
3 to 1	15500
4 to 1	35000
5 to 1	50000

Condition	1	2	3	4	5
1	0.51	0.11	0.37	0.01	0.00
2	0.00	0.54	0.21	0.23	0.02
3	0.00	0.00	0.91	0.08	0.00
4	0.00	0.00	0.00	0.99	0.01
5	0.00	0.00	0.00	0.00	1.00

Figure 8.1: Transition probability matrix of the given building component

<u>Calculation of predicted maintenance cost required annually and for the planned period to maintain the given building component at condition 4</u>

The calculation is mainly based on the percentage change of conditions due to deterioration. Then, the intervention on maintenance occurs at conditions below condition 4, which is only a proportion of condition 5. The proportion of condition 5 is then converted to condition 1. Hence, it is added to the proportion of condition 1 for the next year. A similar strategy can be applied for successive years and annual and accumulated costs can be calculated accordingly. The step-by-step calculation is shown in Table 8.5.

Table 8.5: Calculation of annual and cumulative costs to maintain the given building component at condition 4 during the planned period (10 years here)

Condition	Current year (Year 1)		Year 2		Year 3		Year 4		Year 5	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0.1	0	0.01	0	0.01	0	0.01	0	0.01	0
4	0.2	0.2	0.28	0.28	0.35	0.35	0.41	0.41	0.46	0.46
3	0.3	0.3	0.42	0.42	0.47	0.47	0.48	0.48	0.47	0.47
2	0.25	0.25	0.16	0.16	0.1	0.1	0.06	0.06	0.04	0.04
1	0.15	0.25	0.13	0.14	0.07	0.08	0.04	0.05	0.03	0.04
Annual Cost	5000		500		500		500		500	
Cumulative Cost	5000		5500		6000		6500		7000	
Condition	Year 6		Year 7		Year 8		Year 9		Year 10	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0.1	0	0.01	0	0.01	0	0.01	0	0.01	0
4	0.2	0.2	0.28	0.28	0.35	0.35	0.41	0.41	0.46	0.46
3	0.3	0.3	0.42	0.42	0.47	0.47	0.48	0.48	0.47	0.47
2	0.25	0.25	0.16	0.16	0.1	0.1	0.06	0.06	0.04	0.04
1	0.15	0.25	0.13	0.14	0.07	0.08	0.04	0.05	0.03	0.04
Annual Cost	500		500		500		500		500	
Cumulative Cost	7500		8000		8500		9000		9500	

Calculation of predicted maintenance cost required annually and for the planned period to maintain the given building component at its condition 3

A similar procedure to that applied in the previous section was adopted in the calculation here, the only change being in the condition of intervention on maintenance, which was condition 3. As a result, all proportions of condition 4 and 5 were converted to condition 1, and hence they were aggregated with the remaining proportion of condition 1 for the next year. A similar strategy was applied for successive years and annual and accumulated costs were calculated accordingly. The step-by step calculation is illustrated in Table 8.6.

Table 8.6: Calculation of annual and cumulative costs to maintain the given building component at condition 3 during the planned period (10 years here)

Condition	Current year (Year 1)		Year 2		Year 3		Year 4		Year 5	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0.1	0	0.01	0	0	0	0	0	0	0
4	0.2	0	0.09	0	0.09	0	0.09	0	0.08	0
3	0.3	0.3	0.49	0.49	0.61	0.61	0.68	0.68	0.72	0.72
2	0.25	0.25	0.18	0.18	0.13	0.13	0.1	0.1	0.08	0.08
1	0.15	0.45	0.23	0.33	0.17	0.26	0.13	0.22	0.12	0.2
Annual Cost	12000		3650		3150		3150		2800	
Cumulative Cost	12000		15650		18800		21950		24750	
Condition	Year 6		Year 7		Year 8		Year 9		Year 10	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0	0	0	0	0	0	0	0	0	0
4	0.08	0	0.08	0	0.08	0	0.08	0	0.08	0
3	0.75	0.75	0.76	0.76	0.77	0.77	0.78	0.78	0.78	0.78
2	0.07	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.05
1	0.1	0.18	0.09	0.17	0.09	0.17	0.09	0.17	0.09	0.17
Annual Cost	2800		2800		2800		2800		2800	
Cumulative Cost	27550		30350		33150		35950		38750	

<u>Calculation of predicted maintenance cost required annually and for the planned period to maintain the given building component at its condition 2</u>

A similar procedure to that applied in previous sections was adopted in this calculation. The condition of intervention on maintenance was condition 2. Therefore, all proportions of condition 3, 4 and 5 were converted to condition1. Consequently, all were aggregated with the remaining proportion of condition 1 for the next year and similarly treatments were applied for successive years. Then annual and accumulated costs were calculated according to the treatments in particular years. The step-by-step calculation is illustrated in Table 8.7.

Table 8.7: Calculation of annual and cumulative costs to maintain the given building component at condition 2 during the planned period (10 years here)

Condition	Current year (Year 1)		Year 2		Year 3		Year 4		Year 5	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0.1	0	0.01	0	0	0	0	0	0	0
4	0.2	0	0.07	0	0.06	0	0.05	0	0.05	0
3	0.3	0	0.33	0	0.34	0	0.34	0	0.34	0
2	0.25	0.25	0.22	0.22	0.2	0.2	0.2	0.2	0.2	0.2
1	0.15	0.75	0.38	0.79	0.4	0.8	0.41	0.8	0.41	0.8
Annual Cost	16650		8065		7370		7020		7020	
Cumulative Cost	16650		24715		32085		39105		46125	
Condition	Year 6		Year 7		Year 8		Year 9		Year 10	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0	0	0	0	0	0	0	0	0	0
4	0.05	0	0.05	0	0.05	0	0.05	0	0.05	0
3	0.34	0	0.34	0	0.34	0	0.34	0	0.34	0
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1	0.41	0.8	0.41	0.8	0.41	0.8	0.41	0.8	0.41	0.8
Annual Cost	7020		7020		7020		7020		7020	
Cumulative Cost	53145		60165		67185		74205		81225	

<u>Calculation of predicted maintenance cost required annually and for the planned period to maintain the given building component at condition 1</u>

A similar procedure to that used in previous sections was used for calculations here. The condition of intervention on maintenance was condition 2. Therefore, all proportions of condition 2, 3, 4 and 5 were converted to condition1. Consequently, all were aggregated with the remaining proportion of condition 1 for the next year and a similar treatment was applied for successive years. Then annual and accumulated costs were calculated according to the treatments in particular years. The step-by-step calculation is illustrated in Table 8.8.

Table 8.8: Calculation of annual and cumulative costs to maintain the given building component at condition 1 during the planned period (10 years here)

Condition	Current year (Year 1)		Year 2		Year 3		Year 4		Year 5	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0.1	0	0	0	0	0	0	0	0	0
4	0.2	0	0.01	0	0.01	0	0.01	0	0.01	0
3	0.3	0	0.37	0	0.37	0	0.37	0	0.37	0
2	0.25	0	0.11	0	0.11	0	0.11	0	0.11	0
1	0.15	1	0.51	1	0.51	1	0.51	1	0.51	1
Annual Cost	17775		6580		6580		6580		6580	
Cumulative Cost	17775		24355		30935		37515		44095	
Condition	Year 6		Year 7		Year 8		Year 9		Year 10	
	Current condition percentage	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done	Predicted condition distribution	Percentage distribution after treatment done
5	0	0	0	0	0	0	0	0	0	0
4	0.01	0	0.01	0	0.01	0	0.01	0	0.01	0
3	0.37	0	0.37	0	0.37	0	0.37	0	0.37	0
2	0.11	0	0.11	0	0.11	0	0.11	0	0.11	0
1	0.51	1	0.51	1	0.51	1	0.51	1	0.51	1
Annual Cost	6580		6580		6580		6580		6580	
Cumulative Cost	50675		57255		63835		70415		76995	

8.4 Determining the best intervention times of whole building assets for renewals during the planned period

8.4.1 Background

According to Jernberg et al. (2004), the objective of service life analysis is to establish and explain the performance-over-time functions, which describe how the measured values of chosen performance characteristics are expected to vary with time. Related to buildings, the most viable method of capturing the performance is according to their condition (IPWEA, 2009). Jernberg et al (2004) further explain the performance with a performance criterion which suggests a minimum acceptable performance. Below this level, performance is considered not to be acceptable for the intended function, although the building or component can still be functional or operational. When the performance is captured by the condition, it becomes the minimum acceptable condition for the given building or component.

A deterioration curve represents the condition degradation over time, which can be regarded as a performance indicator over time. Linear variation is assumed for the deterioration in some financial analysis but in reality it is not the actual shape. Deterministic and probabilistic approaches used in deterioration prediction give reasonably close shapes for deterioration, even though they are not the absolute correct shapes. For examples of both methods, IPWEA (2009) shows a deterministic curve because it is the most common approach used by the industry, whereas McDulling (2006) and Mohseni et al (2012b) applied a probabilistic approach and generated probabilistic deterioration curves. Deterioration curves generated in both situations are the combined effect of natural depreciation and depreciation occurring due to other external factors

According to the deterioration curve, whichever way it was produced, service life is the time taken for the complete change from condition 1 to condition 5. However, the building or component does not function at the required level of service during the time below the minimum acceptable condition in the graph. Therefore, the time that shows the change from condition 1 to the minimum acceptable condition is called “useful service life (U)” while service life can be interpreted as "designed life". "Remaining useful life (R)" is another term which correlates with useful life. It can be defined as the time taken for the current condition to reach the minimum acceptable condition. The most important feature of a deterioration curve is that maintenance actions such as minor repair, major repair, renewal or replacement can be correlated with condition change of the curve. Renewals always take the building or component back to condition 1 but major and minor repairs do not necessarily change the condition to 1. This is because renewals are intended to bring the building or component to potentially original level. The decision made on a renewal action is referred to as intervention here.

Figure 8.2 amalgamates all the above facts and gives a clear interpretation of the terms defined above. Several scenarios of interventions can occur, depending on the above terms, but one scenario is particularly referred to in the figure. The only reason for the selection of the scenario in the figure is the clear representation of terms. Other scenarios will be discussed in the rest of the section.

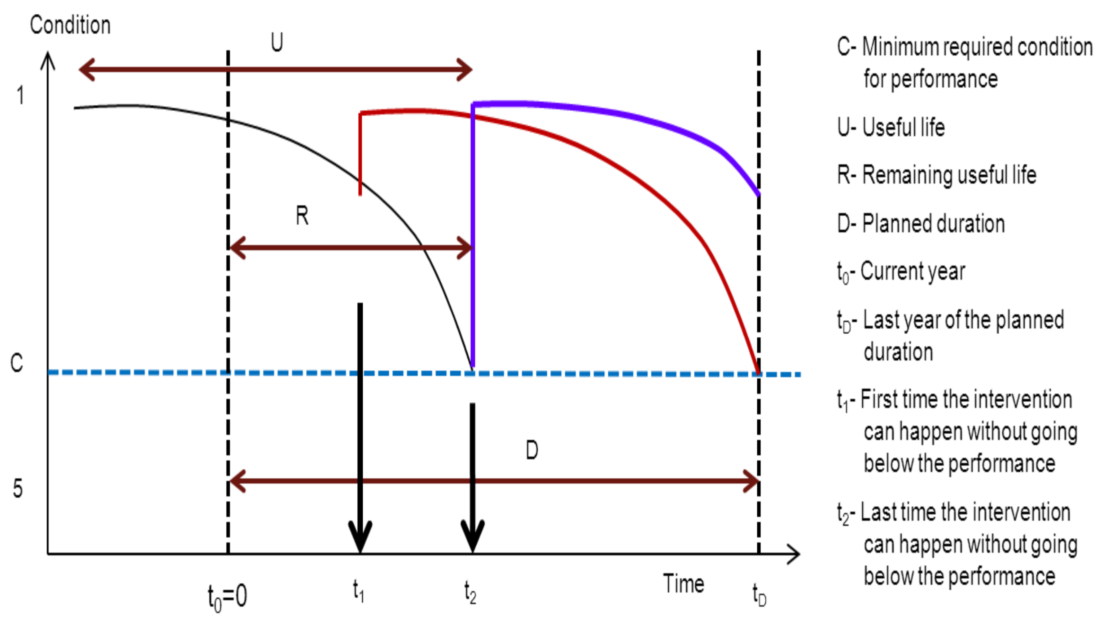


Figure 8.2: Important factors in relation to the determination of the best intervention periods

8.4.2 Determination of best intervention periods for renewals of whole building assets

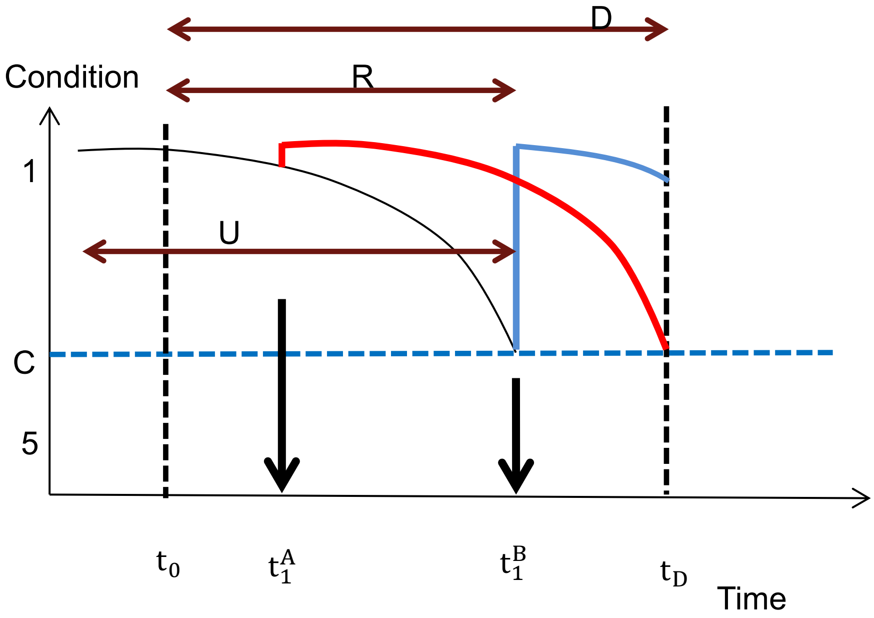
Given that three interventions are the maximum number of interventions expected to occur during the planned period, eight scenarios of interventions come into effect, depending on the variables of useful life (U), remaining useful life (R) and planning duration (D). They are:

- Scenario 1: When $U \leq D \leq U+R$ and $R>0$
- Scenario 2: When $U+R < D \leq 2U+R$ and $R>0$
- Scenario 3: When $2U+R < D \leq 3U+R$ and $R>0$
- Scenario 4: When $D< U$ & $R \leq 0$
- Scenario 5: When $U < D < 2U$ and $R \leq 0$
- Scenario 6: When $2U < D < 3U$ and $R \leq 0$
- Scenario 7: When $R < D < U$ and $R > 0$
- Scenario 8: $D \leq R$ and $R>0$

The best intervention periods related to each scenario are discussed under each scenario below.

Scenario 1: When $U \leq D \leq U+R$ and $R>0$

The scenario and the related best interventions are clearly shown by Figure 8.3 below.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

t_1^A= the first time that the first and only intervention can be done effectively

t_1^B= the last time that the first and only intervention can be done effectively

Figure 8.3: Best intervention periods related to Scenario 1

In the figure, the red curve shows one possibility for maintaining deterioration at above or equal to the minimum acceptable condition. Accordingly, intervention occurs at time t_1^A at which the related specific condition above the minimum acceptable condition is brought to condition 1. Afterwards, it deteriorates normally and reaches the minimum acceptable condition at t_D which is the end of the duration. On the other hand, the blue curve is the other possibility for maintaining deterioration up to the acceptable performance level. According to the figure, the intervention happens at t_1^B at which the related condition is the minimum acceptable condition and it turns to condition 1 through the renewal. After the renewal, it undergoes general deterioration and follows the same shape for general deterioration. It ends with a higher condition than the minimum acceptable condition at the end of the planning duration.

It is obvious that the curves represent two ends of solutions for the same problem. Moreover, the time between t_1^A and t_1^B is the best time to intervene once and maintain the minimum performance by only one renewal. In contrast, renewals beyond that range will require more than one renewal or performance will fall below the acceptable level during the planned period. Times of t_1^A and t_1^B can be acquired through mathematical equations and they are shown as follows.

$$t_1^A = D-U$$

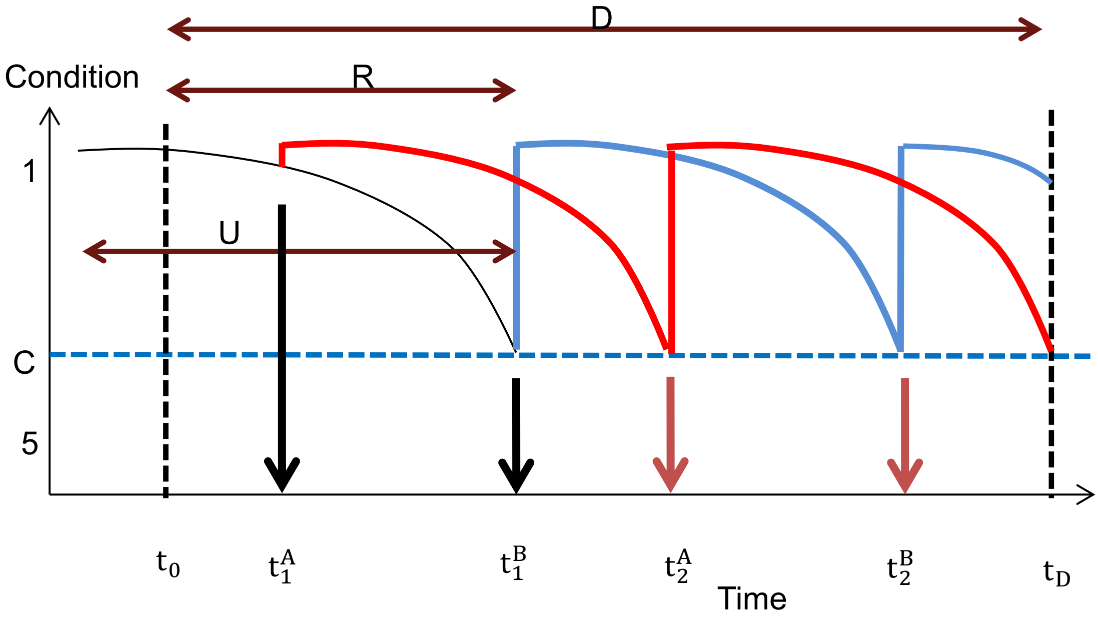
..................Equation 8.1

$$t_1^B = R$$

..................Equation 8.2

Scenario 2: When U+R < D ≤ 2U+R   and R>0

The scenario and related best intervention periods are shown in Figure 8.4.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

t_1^A= the first time that the first intervention can be done effectively

t_1^B = the last time that the first intervention can be done effectively

t_2^A= the first time that the second intervention can be done effectively

t_2^B = the last time that the second intervention can be done effectively

Figure 8.4: Best intervention periods related to Scenario 2

According to the figure, a minimum of two interventions are required to maintain the minimum required performance during the planned period. The best intervention periods are represented by deterioration curves, as in the previous scenario. The red curves represent the feasibility of a first attempt of a particular intervention, whereas the last attempt is represented by blue curves. Hence, the most appropriate time for the first intervention lies between t_1^A and t_1^B whereas it is t_2^A and t_2^B for the second intervention. Each time figure can be acquired mathematically by the following equations.

t_1^A= D-2U

..................Equation 8.3

t_1^B= R

..................Equation 8.4

t_2^A= D-U

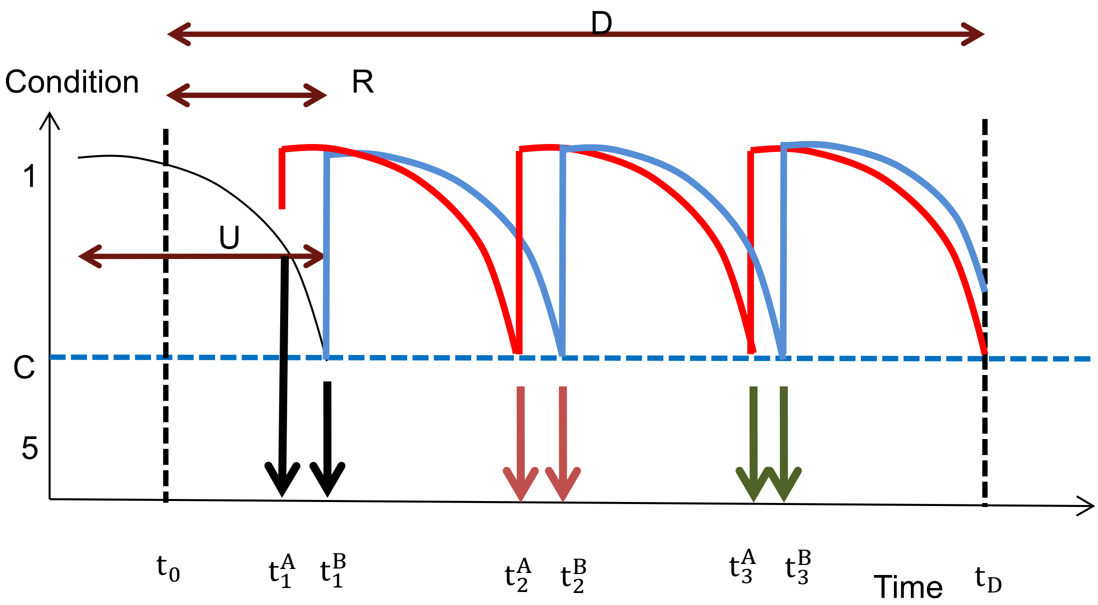
..................Equation 8.5

t_2^B= U+R

..................Equation 8.6

Scenario 3: $2U+R < D \leq 3U+R$ and $R>0$

The scenario and related best intervention periods are shown in Figure 8.5.



Where;

U= Useful life   R= Remaining useful life   D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year   tD= Last year of the planned duration

t_1^A= the first time that the first intervention can be done effectively

t_1^B = the last time that the first intervention can be done effectively

t_2^A= the first time that the second intervention can be done effectively

t_2^B = the last time that the second intervention can be done effectively

t_3^A= the first time that the third intervention can be done effectively

t_3^B= the last time that the third intervention can be done effectively

Figure 8.5: Best intervention periods related to Scenario 3

The best intervention approach is very similar to Scenario 2, but the minimum performance during the whole planned period is not achievable without at least three interventions. The red and blue curves serve for the same features as in the previous scenarios. Therefore, the time interval between t_1^A and t_1^B is the best time for the first intervention. Similarly, the best times for the second and third interventions are in the intervals of t_2^A and t_2^B and t_3^A and t_3^B respectively.

t_1^A= D-3U

..................Equation 8.7

t_1^B= R

..................Equation 8.8

t_2^A= D-2U

..................Equation 8.9

t_2^B= U+R

..................Equation 8.10

t_3^A= D-U

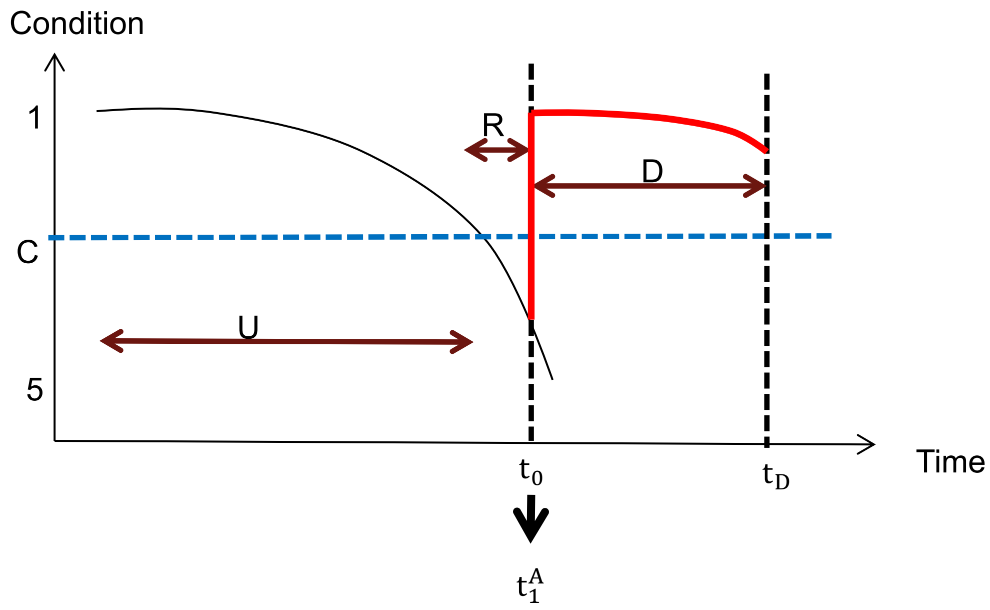
..................Equation 8.11

t_3^B= 2U+R

..................Equation 8.12

Scenario 4: D< U and R ≤ 0

The scenario and related best intervention periods are shown in Figure 8.6.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

t_1^A= the current time that the first and only intervention to be done

Figure 8.6: Best intervention periods related to Scenario 4

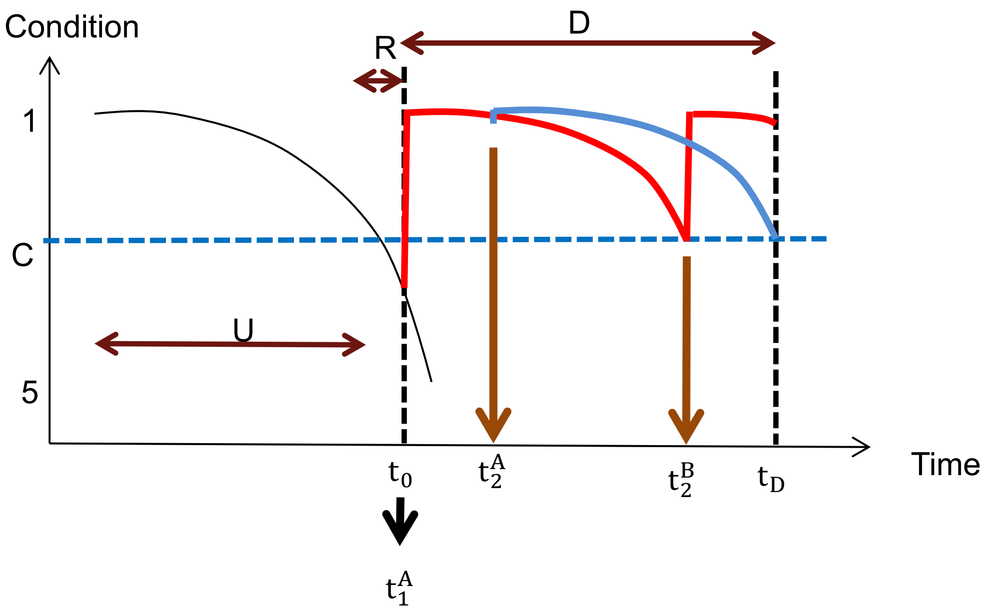
The scenario is one example of a whole building asset which is not currently functioning to the required performance. Although it is not fundamentally acceptable to go below the minimum performance, a situation like scenario 4 is possible in reality. If the situation is prolonged over time, it will reach the worst condition, which means that the whole building is also about to exceed its designed service life. Beyond this point, the building can be regarded as redundant, because it is no longer capable of functioning. This requires the system to renew the building or upgrade the condition to a level at which the building can function. Based on the current scenario, at least one intervention is possible but the optimum use can be obtained if it happens at the current time. All interventions beyond the current time pass some time below the minimum performance over the planned period. The time of the intervention related to the scenario can be shown by the following equation:

$t_1^A = t_0$

..................Equation 8.13

<u>*Scenario 5: U < D < 2U and R ≤ 0*</u>

The scenario and related best intervention periods are shown in Figure 8.7.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

t_1^A= the current time that the first intervention to be done

t_2^A = the first time that the second intervention can be done effectively

t_2^B = the last time that the second intervention can be done effectively

Figure 8.7: Best intervention periods related to Scenario 5

This scenario is very similar to the previous scenario, but more than one intervention is required to maintain the minimum performance over the planned period. The first intervention should undoubtedly occur at the current time. Optimally, the planned duration can be maintained with another intervention which is restricted to occurring between t_2^A and t_2^B. The renewals are illustrated with blue and red curves. The equations required to find the times of interventions are as follows:

$t_1^A = t_0$

..................Equation 8.14

$t_2^A = D\text{-}U$

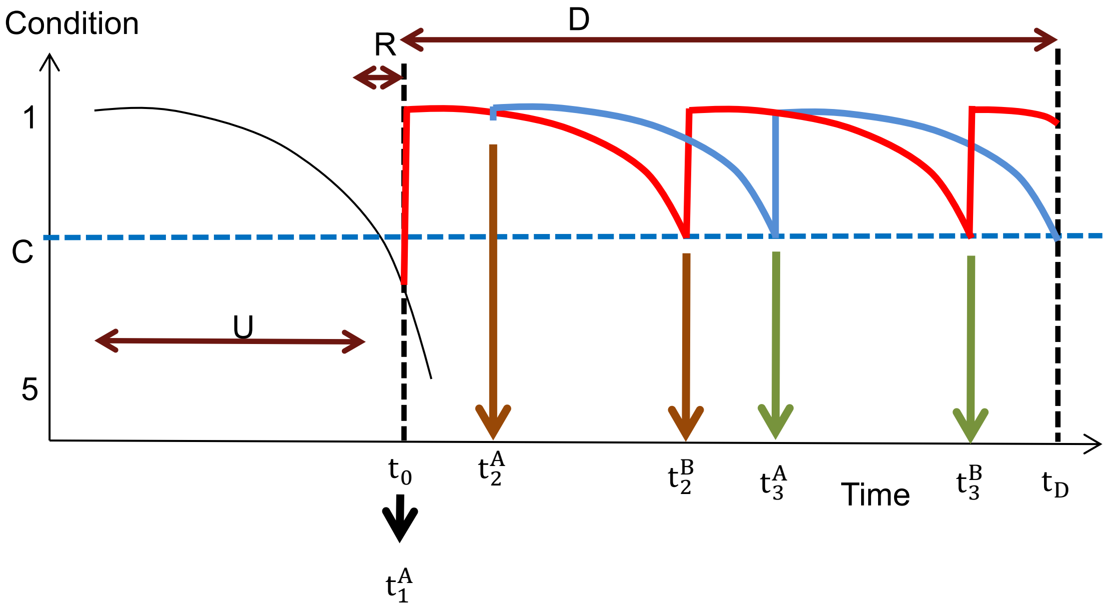
..................Equation 8.15

$t_2^B = U$

..................Equation 8.16

Scenario 6: 2U < D < 3U and R ≤ 0

The scenario and related best intervention periods are shown in Figure 8.8.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

t_1^A= the time that the first intervention to be done

t_2^A= the first time that the second intervention can be done effectively

t_2^B = the last time that the second intervention can be done effectively

t_3^A= the first time that the third intervention can be done effectively

t_3^B= the last time that the third intervention can be done effectively

Figure 8.8: Best intervention periods related to Scenario 6

The scenario is similar to scenarios 4 and 5 but the planned duration is one useful life more than scenario 5 and two useful lives more than scenario 4. As in the previous two cases, the first intervention happens at the current time for this scenario. Two more interventions after the first intervention give the optimum result for maintaining the performance over the planned duration. Accordingly, the second intervention occurs in the range of t_2^A to t_2^B whereas the third intervention lies between t_3^A and t_3^B. The following equations are used to find the time intervals for all interventions:

$t_1^A = t_0$

..................Equation 8.17

$t_2^A = D\text{-}2U$

..................Equation 8.18

$t_2^B = U$

..................Equation 8.19

$t_3^A = D\text{-}U$

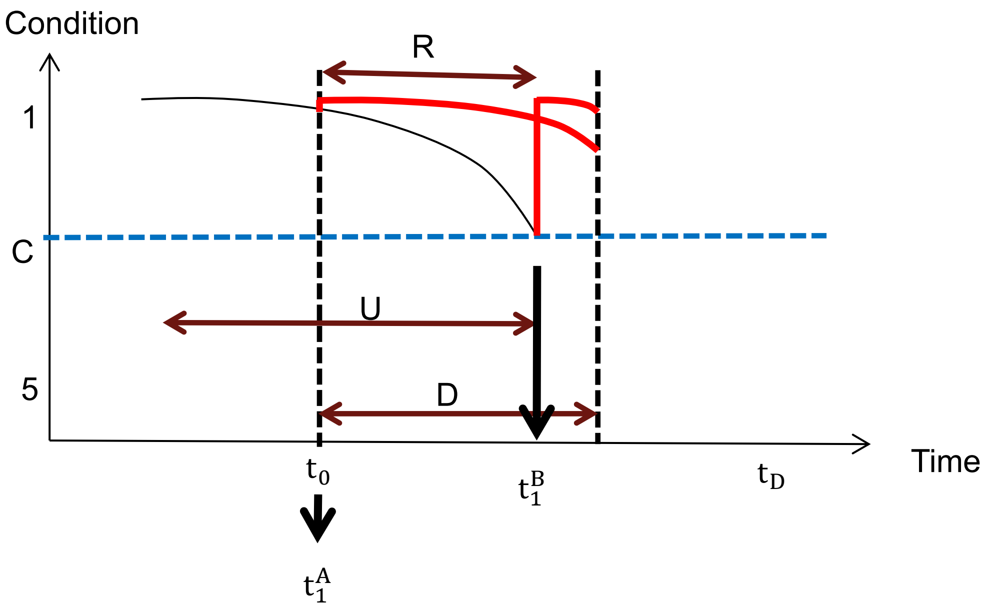
..................Equation 8.20

$t_3^B = 2U$

..................Equation 8.21

Scenario 7: R < D < U and R > 0

The scenario and related best intervention periods are shown in Figure 8.9.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

t_1^A= the first time that the first and only intervention can be done effectively

t_1^B= the last time that the first and only intervention can be done effectively

Figure 8.9: Best intervention periods related to Scenario 7

The figure indicates that the building cannot be maintained at the minimum required condition of performance without at least one intervention. The last possibility of optimal use of that intervention ends at time t_1^B so that the first intervention can happen at any time between the current time and t_1^B. Hence, the time interval best suited for the first intervention can be obtained using the following equations:

$t_1^A = t_0$

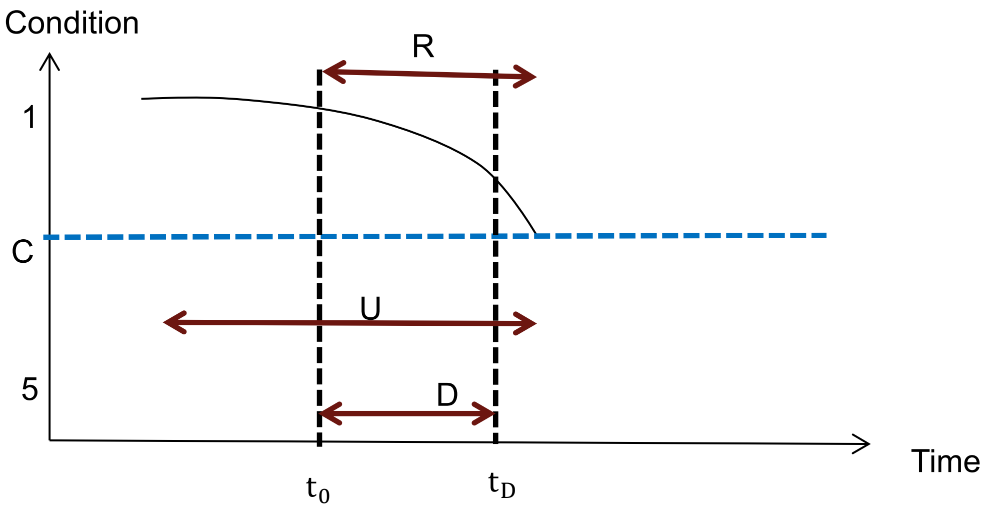
..................Equation 8.22

$t_1^B = R$

..................**Equation 8.23**

Scenario 8: D ≤ R   and R>0

Figure 8.10 clearly shows that no intervention is required over the planned period.



Where;

U= Useful life R= Remaining useful life D=Planned duration

C= Minimum acceptable condition for performance

t_0= Current year t_D= Last year of the planned duration

Figure 8.10: Best intervention periods related to Scenario 8

Summary of results for best intervention periods related to selected scenarios

The following table summarises all the results related to each scenario.

Table 8.9: Details of interventions in relation to different scenarios of U, R and D

Scenarios	Description about intervention during the planned period	Intervention period		
		1st intervention	2nd intervention	3rd intervention
1. $U \le D \le U+R$ and $R>0$	One intervention	$t_1^A = D-U$ $t_1^B = R$		
2. $U+R < D \le 2U+R$ and $R>0$	Two interventions	$t_1^A = D-2U$ $t_1^B = R$	$t_2^A = D-U$ $t_2^B = U+R$	
3. $2U+R < D \le 3U+R$ and $R>0$	Three interventions	$t_1^A = D-3U$ $t_1^B = R$	$t_2^A = D-2U$ $t_2^B = U+R$	$t_3^A = D-U$ $t_3^B = 2U+R$
4. $D < U$ & $R \le 0$	One intervention	$t_1^A =$ Current year		
5. $U < D < 2U$ and $R \le 0$	Two interventions	$t_1^A =$ Current year	$t_2^A = D-U$ $t_2^B = U$	
6. $2U < D < 3U$ and $R \le 0$	Three interventions	$t_1^A =$ Current year	$t_2^A = D-2U$ $t_2^B = U$	$t_3^A = D-U$ $t_3^B = 2U$
7. $R < D < U$ and $R > 0$	One intervention	$t_1^A =$ Current year $t_1^B = R$		
8. $D \le R$ and $R>0$	No interventions	No interventions		

8.4.3 Concluding remarks

This chapter has discussed three integrated decision-making aspects which are significant to the sustainable management of community buildings. The present research has developed a model for prioritising the building components for maintenance activities. The decision is made based on the sustainability index values generated by the model. A detailed clarification of the ranking process has been given in this chapter in conjunction with related values based on data from two case studies. The second aspect discussed was optimising cost in maintenance activities under ongoing deterioration. A program was created for this purpose using Excel ©. An explanation of the use of the program has been given with the support of a hypothetical example. The last aspect discussed was the determination of the best intervention times for the renewals of whole building assets. Diagram illustrations followed by clear descriptions derived the best time periods for renewal interventions of whole building assets based on the eight available scenarios.

9 SOFTWARE TOOL: COUNCIL ASSET MANAGEMENT SOFTWARE (CAMS)

9.1 Introduction

The main intent of developing the software (Council Asset Management Software) (CAMS) tool was to provide a user-friendly tool to end- users of this industrial project who work in community building management. It was designed based on the outcomes generated during the project, which addresses major concerns in relation to community building management. Two main concerns were the need to develop a reliable deterioration prediction module and a decision-making module to prioritise building components for sustainable maintenance activities. The former concern was beyond the scope of the current research and it was the focus of another PhD study in a parallel research study in the industrial project (Mohseni, 2012). The latter concern was a focus of the present research and it is addressed in this chapter. Consistent with respondents' major concerns, the software focuses on maintaining building management data using in-built modules for different inventory data. The inventory modules include building registry and component registers but also to inspection management and maintenance management registers, which are discussed in subsequent sections. Figure 9.1 shows all inventory modules and analysis modules of the software.

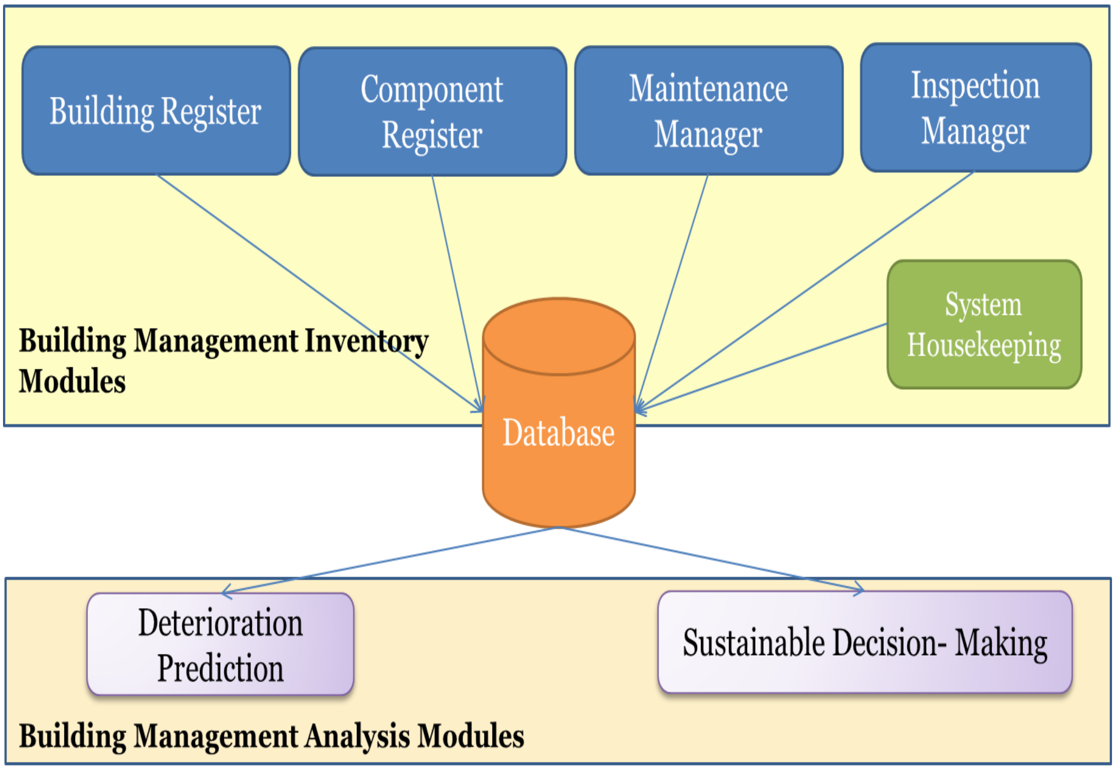


Figure 9.1: Main modules of the software

9.2 Overview of the software

The software was created on the web using Microsoft ASP.net, which allows users to log in to the software through the web and input and store their data in the cloud. Some modules of the software include default arrangements and have flexibility to change to user-defined arrangements. For example, the default elemental hierarchy is the NAMS (IPWEA, 2009) hierarchy but it can be changed according to the hierarchies councils prefer. The software works through modules assigned to different aspects related to community building management. It first captures inputs and records them in the modules displayed in the main menu which are related to building management inventory. Then it addresses the main aspects, which are deterioration prediction and sustainable decision-making, manipulating those inputs and records, if necessary with the aid of imports by the user. A screen shot of the main menu and the login screen is depicted in Figure 9.2.

Figure 9.2: Main menu of the software

The potential users of the software are as follows:

- Staff of local councils responsible for community building management
- Building inspectors who carry out building inspections and import inspection data into the software

- RMIT researchers and the software developer who take part in testing and further improvements of the software

Figure 9.3 shows the user profile and key outputs of CAMS.

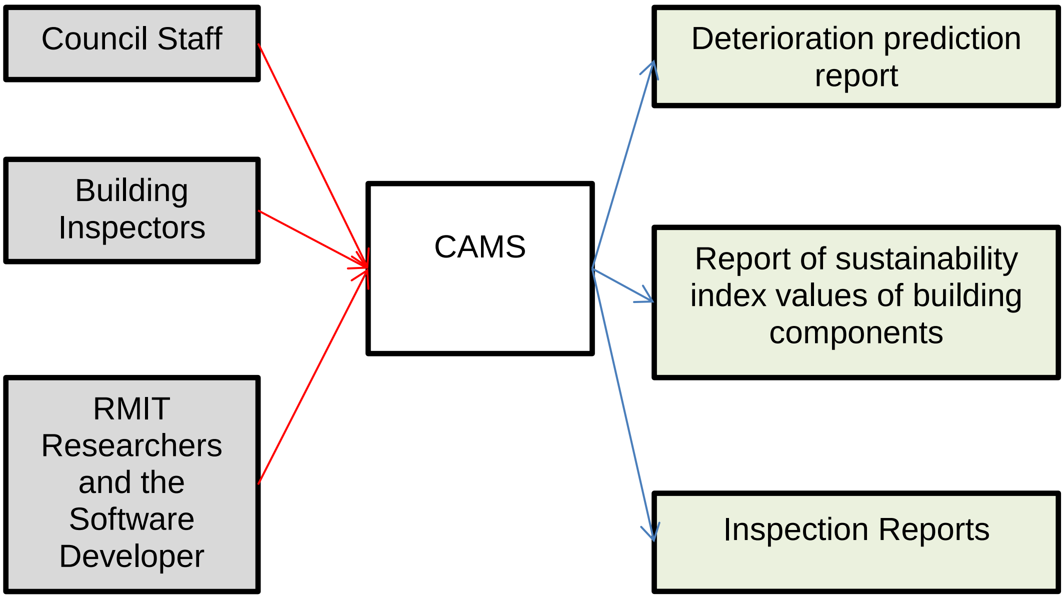


Figure 9.3: User profile and key outputs of CAMS

9.3 Inventory module functions

9.3.1 Building Register

Prior to the module being developed, the following assumptions were made.

- Each council has multiple buildings used for diverse services
- Each building is identified by the type of the building such **as aged care centre, child care centre, library, sports centre** and so on.
- Knowledge of the **building class*** of the building may be useful for deterioration trends and decision-making
- Different functional areas are provided in the same building; for example, **service desk, group study rooms, seminar rooms, book shelving areas** and so on for a **library building**

***= Building class is a term used in the Building Code of Australia regarding the building occupancy, type of design and construction**

Based on the above, the building registry functions in CAMS as follows:

- ✓ Building Type is entered by:
  - Building Type Name
  - Description/Remarks
- ✓ Functional Area Type is entered by:
  - Functional Area Type Name
  - Description/Remarks
- ✓ Building Information is entered by:
  - Building Type
  - Building Class
  - Building Name
  - Description/Remarks
- ✓ Building Functional Area is entered by:
  - Building Type Name
  - Building Name
  - Functional Area Type
  - Functional Area Name
  - Description/ Remarks

In addition to the manual entry of data as indicated above, CAMS also provides the facility of importing formatted data files into the system. In other words, council professionals can enter their data in Excel © files.

9.3.2 Component register

Similar to the previous module, several assumptions were made prior to developing the component registry as follows:

- ✓ Each building has multiple “Building Components” belonging to a “Functional Area”
- ✓ Building components are categorized under “Building Component Types”
- ✓ Building Component Types can be identified under the category of “Building Component Groups”

The module of component register functions as follows:

- Component Class
  - Name
  - Description
  - Component Type ID
  - Age (given by year established)
  - Quantity
  - Material
  - Component Type
  - Name
  - Description
  - Component Group ID (optional)
  - Material
- Component Group
  - Name
  - Description
- Component used in a building (Building Component)
  - Component Class ID

- Functional Area ID
- Description
- Year established
- Quantity
- Material

- Component type used in a building (Building Component Type)
    - Component Type ID
    - Description
    - Year established
    - Quantity
    - Material

The facility of importing Excel © data sheets is also available for the component registry in CAMS.

9.3.3 Inspection Manager

Under the module Inspection Manager, each component is assigned a pre-defined condition rating for use in inspections. The module has been designed based on the condition rating scale 1 to 5. Any council uses condition rating of 1 to 10 has to be converted to 1 to 5. Also, the module assumes that inspections happen regularly, either every year or at a specific time interval set by the council. Hence, components have multiple inspection records for different time periods. However, as some inspection data are provided at only the component type level, maintenance and other management decisions are taken according to those data.

Based on the above, the module functions as follows:

- Manage condition data (add/delete/edit)
- Import condition data for a given period (i.e. 1 year)

- View with filters. Filtering can be done on the basis of:
    - Year
    - Condition rating
    - Building/Component type
- Produce inspection sheets on Excel ©
- Inspection records are tracked by
    - Date of inspection
    - Assessor name
    - Component or Type assessed
    - Rating (1 to 5)
    - Comments
    - Remarks on defects, severity etc.

9.3.4 Maintenance Manager

Basically, Inspection data is the main base used for maintenance. According to the inspection data, components or component types may require different maintenance actions. Therefore, the software provides multiple maintenance records with different time stamps. Maintenance records usually provide descriptions of the maintenance activities and the change of conditions after the maintenance.

The Maintenance Manager module in CAMS functions as follows:

- Manage maintenance data (add/delete/edit)
- Import maintenance data for a given period (i.e. year)
- View with filters. Filters are based on:
    - Date range

    - Condition rating
    - Building/Building Type
    - Component or Component Type
- Maintenance records are tracked by
    - Date of maintenance
    - Maintenance category
    - Component or Component type affected
    - Rating after the change (1 to 5)
    - Description of activity
    - Cost
    - Remarks

9.4 Sustainable decision-making module

The module provides four functional tasks (Tabs) for the calculation of the sustainability index of a given building component. They are:

- Weightings
- Download impact value template
- Upload impact values (m/n)
- Sustainability index

Under the task of **weightings**, the councils are given the choice of assigning the weighting values for sustainable aspects and their criteria in two paths. One path assigns the default weighting values captured by the research. For example, weighting values depicted by Table 5.21 are assigned for four sustainable aspects according to the default mode. The other path calculates the weighting values based on the data provided by the council for questionnaires in-built in the module. The questionnaires are designed to cover all aspects and their criteria, and ask the councils to rank aspects or criteria based on their preferences. Then, using the rank-sum method, the program calculates the weighting values for each aspect and their criteria. Since these weighting values are selected according to the user's preference, this path is called the user-defined mode.

Initially the module displays the default values for aspects and criteria. However, by clicking the user-defined tab, the user can import the questionnaires and assign the user-defined weighting values based on the responses given to the questionnaire. Figure 9.4 shows the screen view of the default mode under weightings, which initially appears once the tab (weightings), is clicked. Figure 9.5 shows the questionnaire which appears related to aspects when the users want to use weighting values based on their preferences by clicking the user-defined tab. Similarly, questionnaires related to environmental, economic, social and functional criteria under the user-defined mode are shown in Figures 9.6 to 9.9 respectively.

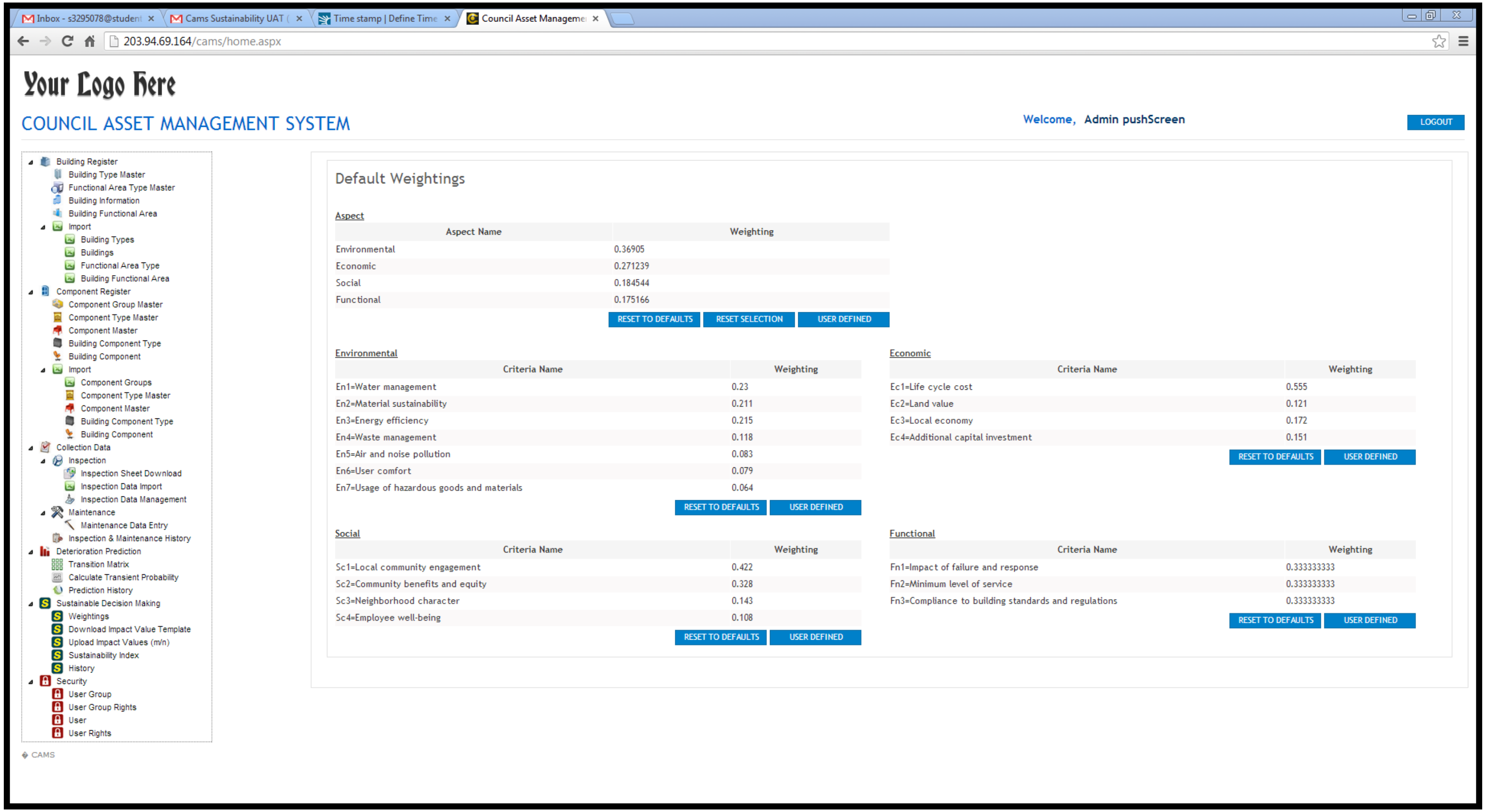


Figure 9.4: Default weightings of the module

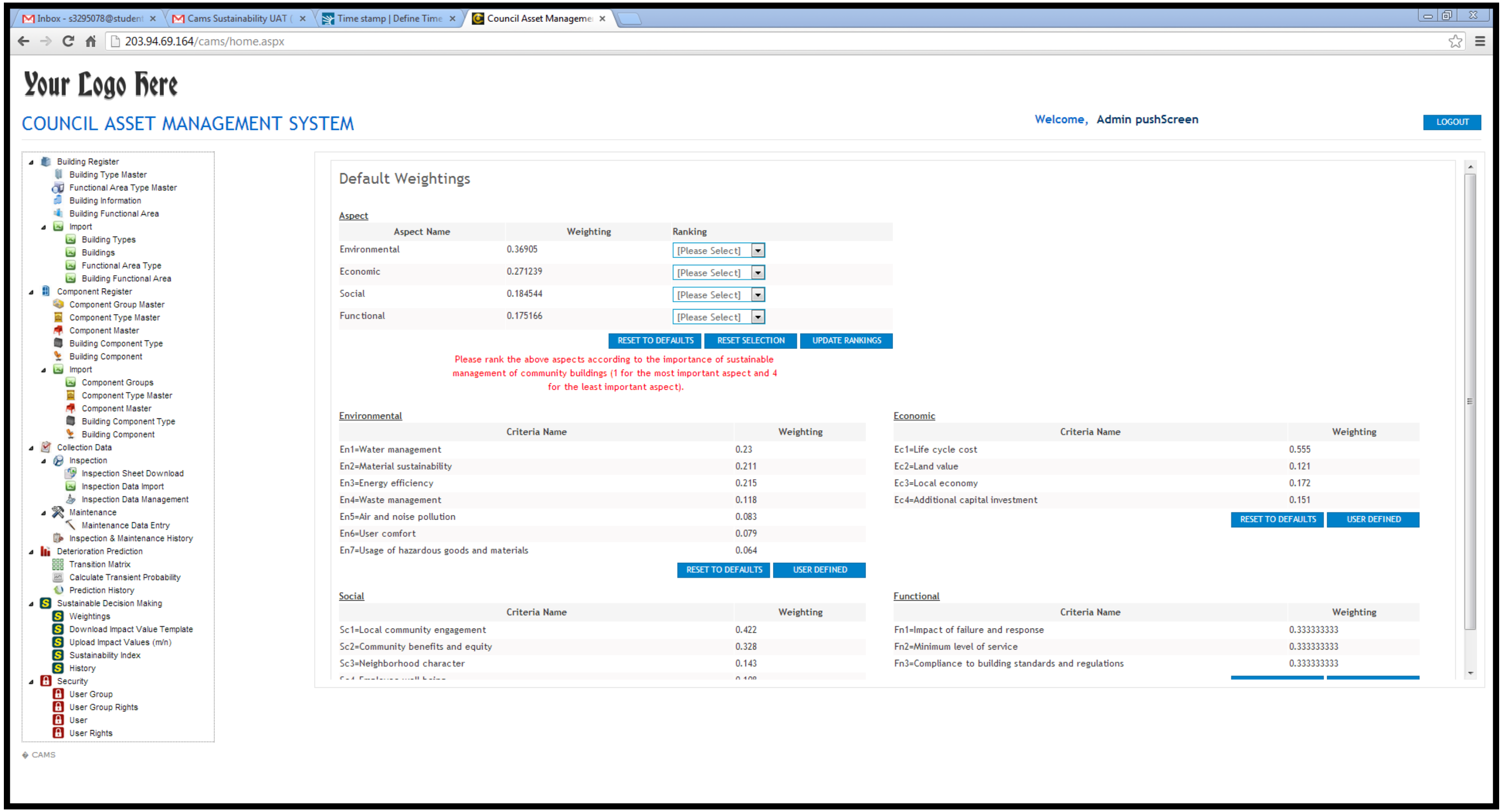


Figure 9.5: Questionnaire related to sustainable aspects

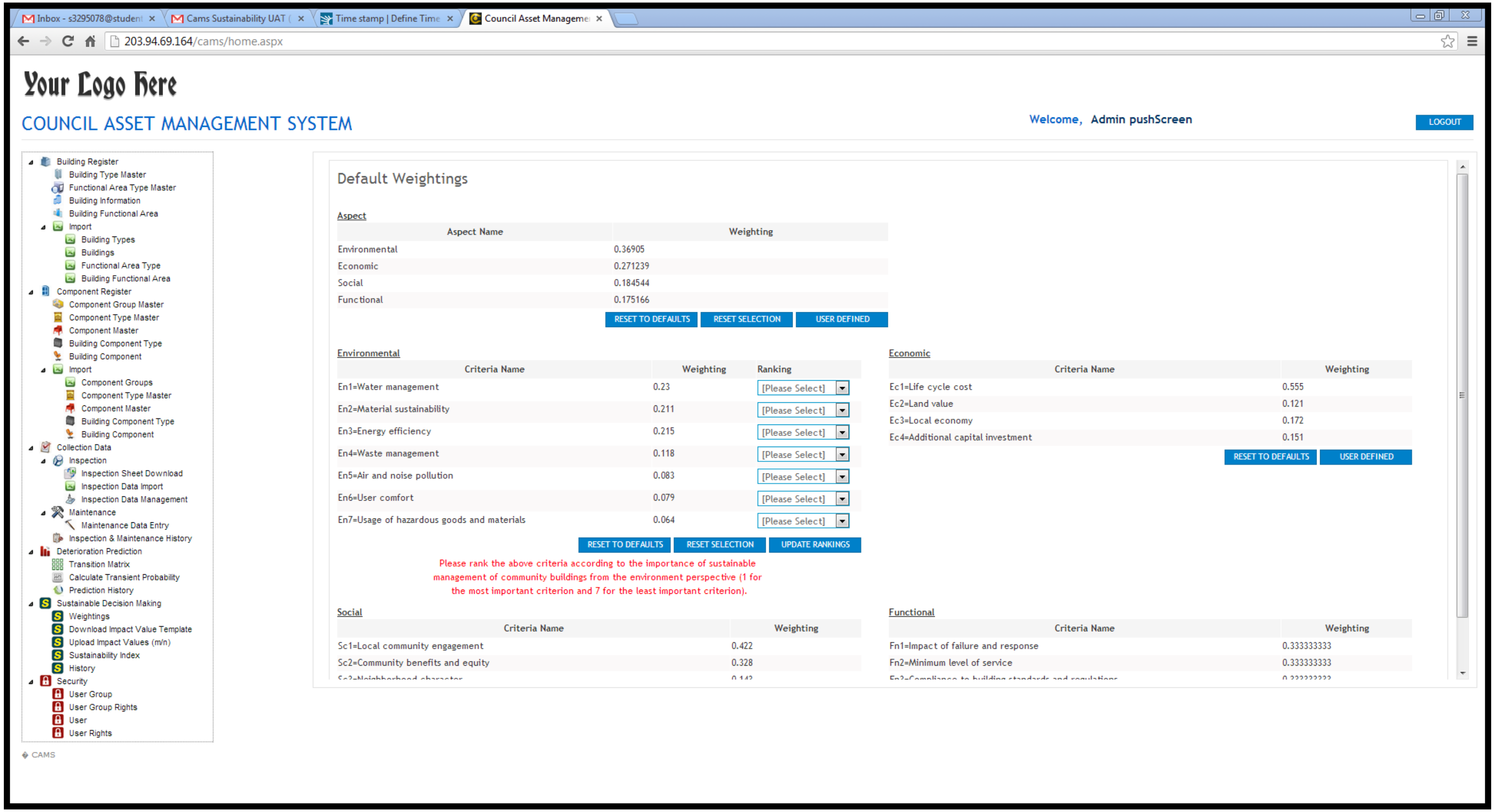


Figure 9.6: Questionnaire related to environmental criteria

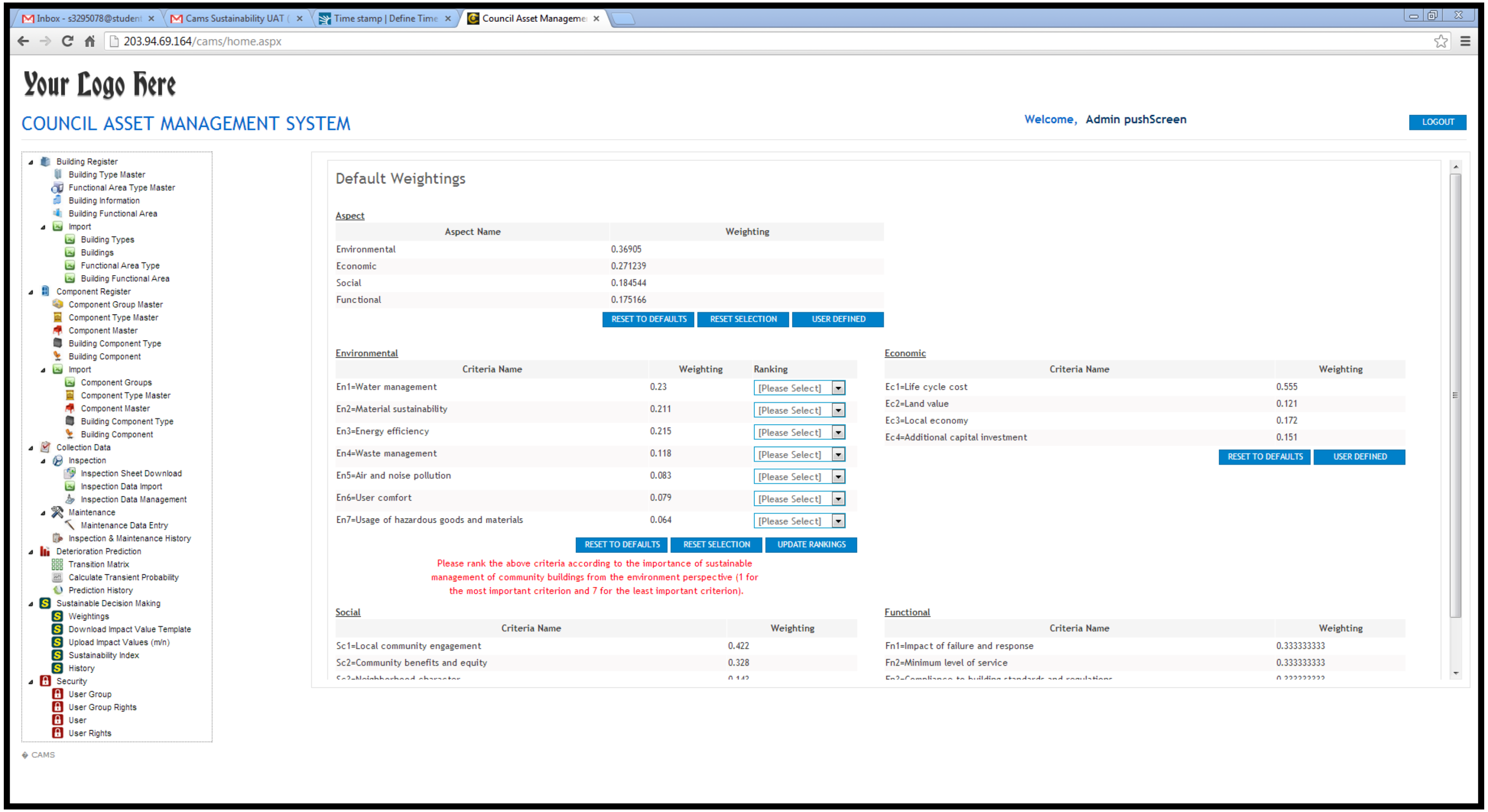


Figure 9.7: Questionnaire related to economic criteria

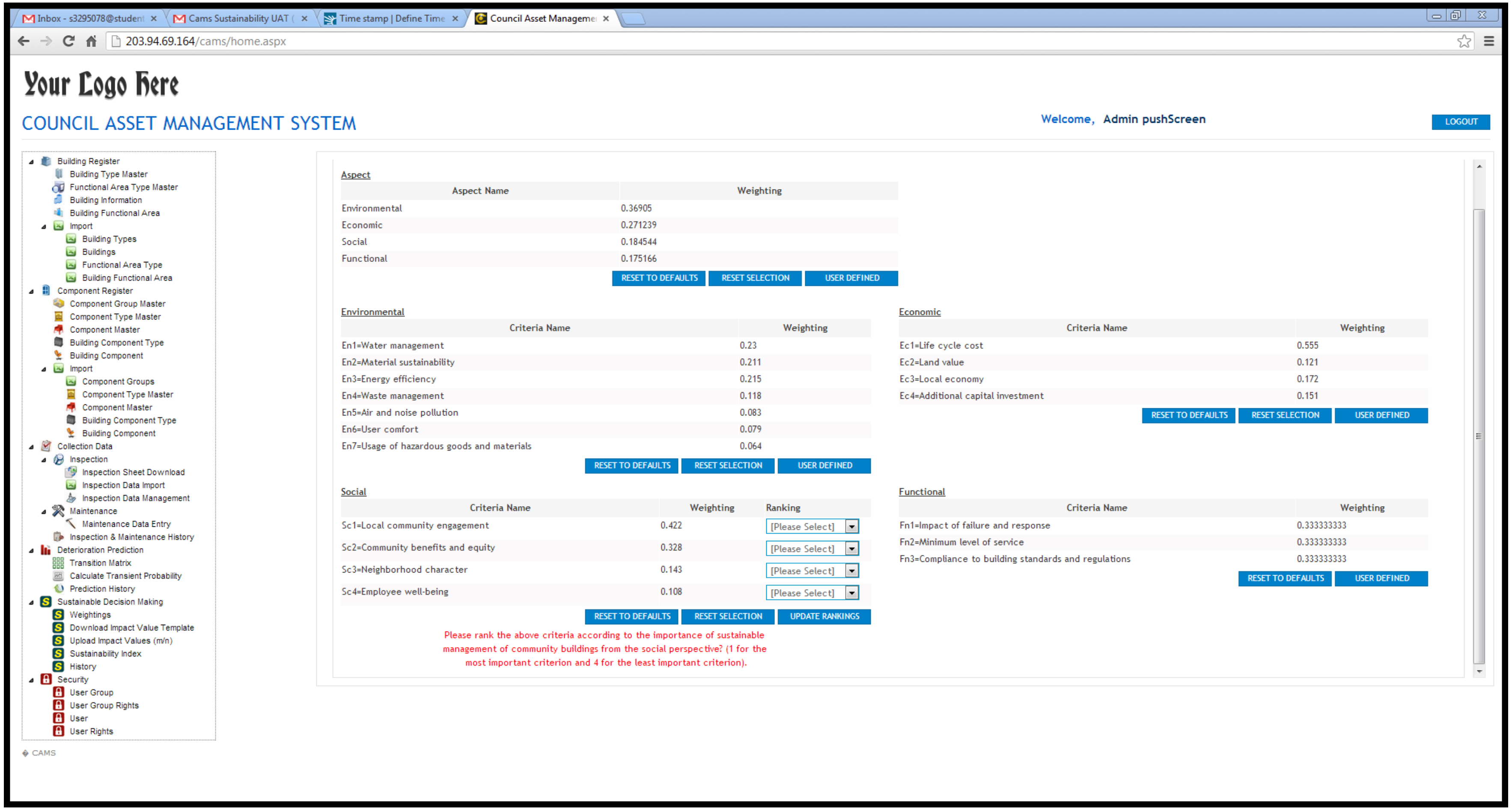


Figure 9.8: Questionnaire related to social criteria

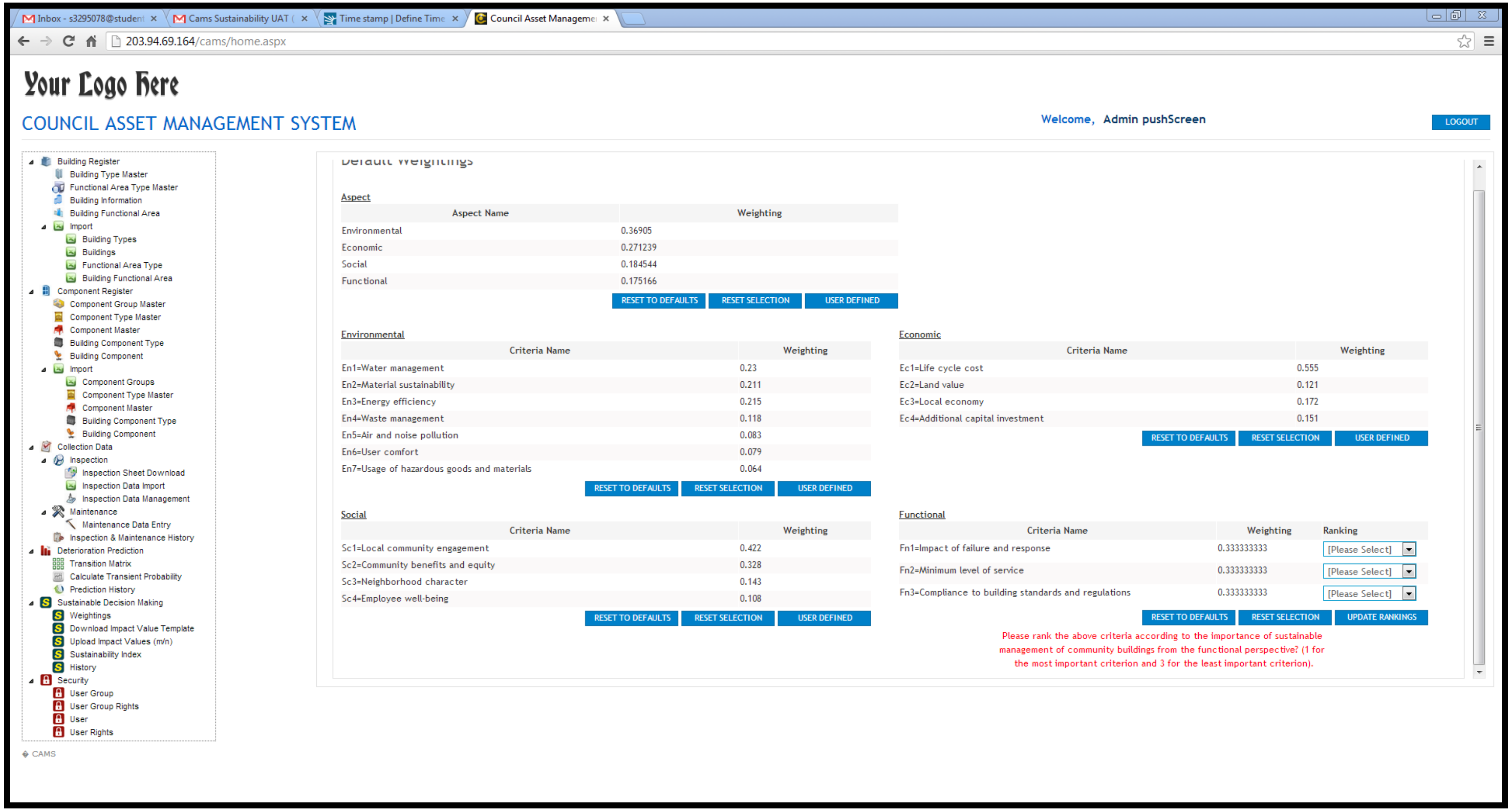


Figure 9.9: Questionnaire related to functional criteria

After weighting values are finalised, the next step is to download the impact value template. Template is in Excel © format and it is extracted based on the component master of the software. The final template shows all 18 criteria against each component. Furthermore, the template provides two sub-categories (columns) under each criterion for the user to enter impact values on the criterion by the given building component at its best and worst condition. Table 9.1 shows the impact value template generated for one partner council. After downloading the template, local councils need to input values to the template according to the way they find impacts to their building components. This process is rather tedious and time-consuming. However, this is a once-only data entry process, unless new building components are added to the system. Once the impact data is entered, it should be uploaded to the system. Then, the system automatically generates the sustainability index values (sustainability impact values) for all building components of the system. The sustainability index tab provides this function. In generating sustainability index values, the system takes into account the condition data of building components. The condition data are obtained by tracking the data uploaded in the inspection module.

Table 9.1: Template for uploading impact values

Building Type	Building Name	Functional Area Type	Functional Area Name	Component Group	Building Component Type	Building Component	Environmental Aspect														Economic Aspect								Social Aspect								Functional Aspect					
							Water management		Material sustainability		Energy efficiency		Waste management		Air and noise pollution		User comfort		Usage of hazardous goods and materials		Life cycle cost		Land value		Local economy		Additional capital investment		Local community engagement		Community benefits and equity		Neighbourhood character		Employee well-being		Impact of failure and response		Minimum level of service		Compliance to building standards and regulations	
							m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n	m	n

Note: m- Impact value at the worst condition of the component

n- Impact value at the best condition of the component

9.5 Summary

The software stands as an interface between the research team and the industry in order to facilitate delivery of the research outcomes to the end-users. . CAMS addresses not only common needs of community building practitioners, such as maintaining building registries, inspection data and maintenance data, but also specific needs such as deterioration prediction and sustainable decision-making. The chapter has illustrated the building management inventory modules (Building Register, Component Register, Inspection Manager and Maintenance Manager), which are common needs of the users. It has demonstrated only sustainable decision-making of the building management analysis modules (under the specific needs category) because this was the author's intended research outcome. The software can be accessed by subscribing through the web, which makes inspections and condition monitoring processes easier. Also, it enables councils to access the information at any time and edit it where necessary. Another added advantage of the software is the flexibility of using the modules via either the default settings or establishing user-defined settings. The software tool is currently in the implementation phase across the partner councils and it is planned to complete it by mid- 2014. The principal leaders of the research program (Associate Professor Sujeeva Setunge, Associate Professor Guomin Zhang, and Professor Ronald Wakefield) then plan to distribute the tool to other local councils in Australia, following consultation with the Municipal Association of Victoria (MAV).

10 CONCLUSIONS, CONTRIBUTIONS AND FUTURE RECOMMENDATIONS

10.1 Introduction

The purpose of the present thesis was to develop an integrated decision-making model for the sustainable management of community buildings and Chapter 1 highlighted the problem identification and the research objectives. Current industry practice was explored in an intensive literature review in Chapter 2. Chapter 3 focused on the development of an appropriate research approach, including two industry-wide questionnaires. Chapters 4 and 5 presented the data analysis and findings of the two questionnaires, respectively, and Chapter 4 inspired the development of a comprehensive decision-making hierarchical structure for the sustainable management of community buildings. Chapter 5 measured the weightings of the branches of the hierarchical structure and the results suggested for the default weighting values of the branches used in the decision-making model. Chapter 6 explained the development of the decision-making model, based on the established hierarchical structure, and Chapter 7 reported on the model's verification, validation and demonstration. Chapter 8 gave a detailed discussion of integrated decision-making approaches based on the outcomes of the research, and Chapter 9 incorporated the outcomes of the industrial linkage project in a software tool for the industry, called CAMS.

The thesis concludes with Chapter 10, which presents the achievements of the research objectives in the form of conclusions and contributions. It also identifies future research areas pertinent to the present research and makes recommendations for future research.

10.2 Conclusions with regard to objectives

10.2.1 Conclusion 1: Development of a comprehensive decision-making structure to address the sustainable management of community buildings

As research studies on community buildings were very few in number their sustainable management was compared with buildings in general. Chapter 2, literature review on the topics of sustainable development and sustainable buildings, suggested that four aspects of sustainability are influential in the sustainable management of buildings: environmental, economic, social and functional. The feedback received from the local councils associated with the research verified their applicability to the sustainable management of community buildings. Building assessments and building management models currently available, discussed in Chapter 2, show several influential factors for the selected sustainability aspects.

In practice, the list was too large (more than 10 factors for each aspect) to manage in a model. The refinement of factors was the solution, and the first industry-wide questionnaire was circulated to local councils in Australia. The results of the questionnaire and the use of factor analysis pinpointed 18 criteria to represent the sustainable management of community buildings in all four sustainable aspects. The results and findings on the 18 criteria have been presented in Chapter 4. The researcher then formulated a comprehensive three-level hierarchy to address the sustainable management of community buildings which was later used for decision-making.

10.2.2 Conclusion 2: Development of a decision making model (sustainability index) for sustainable management of community buildings

Knowledge of the extent of impacts on sustainability caused by the building components of community buildings is another way of expressing the level of sustainable management of community buildings. The researcher has developed a model to capture the sustainability impacts caused by building components with the aid of two analytical tools: AHP and Neuro fuzzy systems and the derived hierarchy. The model was developed using two methods, of which one incorporated AHP. The other model used a combination of AHP and Neuro fuzzy systems. Both methods are explained in Chapter 6 and the output results from either model give the total sustainability impact caused by the building components with a score of 1 to 5. The score is called the sustainability index of the building components. Based on the scores, decision-making on the prioritization of building components for maintenance activities can be implemented, which is discussed in the next conclusion.

10.2.3 Conclusion 3: Prioritization of building components for maintenance activities using the sustainability index model

The sustainability index value generated from the model is an indication of the level of impact on sustainability caused by building components. The level is captured linguistically by the terms “very high impact”, “high impact”, “medium impact”, “low impact” or “very low impact”. Each linguistic level is assigned a range of scores, such that a score is not only another version of the linguistic representation of impact but also a distinctive figure enabling a decision as to the impact level. When main activities are planned, the budget is the most critical factor, but current practices subjectively decide the priority of building components for maintenance activities. In this regard, the sustainability index provides an objective way to make decisions based on priority. The sustainability index is a thorough focus on corporate sustainability. However, the index of a particular sustainability aspect (environmental, economic, social or functional) can be used for the purpose if a particular council is not interested in corporate sustainability. Two case study data is presented in Chapter 7 showing index values in aspect basis and also corporate basis hence prioritisation can be done either way; basis of aspects or corporate.

10.2.4 Conclusion 4: Development of a program to optimize the maintenance cost

The allocation of the cost of maintenance activities is finalized on the basis of several factors, including the time duration of the planned maintenance, on-going deterioration and the minimum performance level (minimum condition) maintained during the planned period. The research has developed a program employing those factors, which shows in Chapter 8, in order to minimise the cost and effectively manage the facilities. Excel © calculations are generated by the program which produces annual and cumulative costs during the planned period.

10.2.5 Conclusion 5: Development of a method to determine optimum intervention times for renewals of whole building assets

Most asset managers are curious as to how to best answer the following question:

What are the best times to intervene for renewals of whole building assets during a planned period?

In Chapter 8, a method has been proposed following the deterioration prediction curve of the building asset. Different scenarios for selected variables of the deterioration curve have been considered in the method. On the assumption that performance does not go below the threshold level, the method provides optimum time periods for each intervention.

10.3 Contributions

To the author's knowledge, this is the first study undertaken specifically to address the sustainable management of community buildings in Australia. The study has contributed to filling gaps in knowledge as well as to improving practice in the industry as follows:

- **No robust studies** exist in the research **literature** which identify the key parameters influencing the maintenance and renewal of community buildings, particularly from a sustainability perspective:

Many studies focus on the triple bottom-line aspects of sustainability (aspects of environmental, economic and social) while fewer studies recommend incorporating the functional aspect, in order to understand total sustainability. In actual practice, existing studies have mainly focused on environmental assessments, and include only limited considerations of other aspects. In other words, none of the assessments in the current literature consider all four aspects of sustainability. Particularly in the context of community buildings, the problem is far worse, since there is no holistic approach to administering the problem. The researcher has explored a broad range of influencing parameters for the management of community buildings on all four sustainability aspects. Then the researcher established a comprehensive hierarchical structure for the sustainable management of community buildings using factor analysis. Most notably, this is the first study dedicated to this purpose.

- **Asset managers in local councils** are in **urgent need** of an **integrated decision-making model** to support their management of community buildings:

The study has contributed to several aspects of the practice in relation to the management of community buildings. A decision-making model has been developed, to enable building components to be prioritised for maintenance activities based on the sustainability index. Not only in management but also in planning and the design, the sustainability index can be used in situations where upgrading or complete replacement of building components occur. The study has also delivered the ability to optimize maintenance activities by developing a program. Finally, the study has proposed a method for the determination of the best intervention times for the renewals of whole building assets.

Apart from the above contributions, the linkage project has integrated the building management framework in a software tool (CAMS) which has the capacity to fulfil the following requirements of the industry:

- ✓ Building Registry and Component Registry allow for inventory of building assets. The inventory identifies the buildings using a hierarchical structure of components
- ✓ Inspection Manager gives the capability of feeding the condition data according to the defined building hierarchy
- ✓ Stochastic deterioration models are used to forecast deterioration of buildings, component groups or components
- ✓ Prioritisation of building components for maintenance activities through a sustainable decision-making module

10.4 Study limitations

The study has limitations in research methodology and also the application of the developed model. In the methodology, impact values were captured introducing linguistic terms for the impact and then translating them into numbers. The method explained how to carry out the process of linguistic term definition for each criterion more objectively. However, a practical approach has not been taken during the research. Each participating council has different perceptions of building management and defining the linguistic terms is time-consuming. More research studies are required to standardize the definitions which most local councils use. Also, the current research was able to obtain only the impact values from one partner council. The idea is so new that it would take a long time to obtain impact values from local councils. However, the implementation of the software tool is currently underway, and it will be easier to capture this information in future. Also, the NAMS (IPWEA, 2009) building hierarchy is currently being applied by many local councils in Australia, making actual impact values based on the NAMS hierarchy obtainable in future. The current research adopted a hypothetical case study for the impact values based on the NAMS hierarchy.

10.5 Recommendations for future research

The current research has shed new light on the sustainable management of community buildings. However, there exist several potential improvements due to either the limitations of the study or being beyond the scope of the present study. The recommendations for future research are as follows:

- Implement the research outcomes in partner councils

The next phase of the industrial project is to implement the outcomes in partner councils for their actual practice. The sustainable decision-making model is very new in terms of their actual practice and the change will require some time. Future researchers could be involved and adjust the system to achieve the targets. In this regard, they can take more methodical approaches to the standardisation of impact data for different local councils using case studies. Similarly, case studies can be utilized to implement the approach to cost optimization for maintenance activities. Moreover, future researchers can engage in interventions in actual practice for the renewals of whole building assets and validate the method accordingly.

- Determine a specific time rather than a time interval to best intervene for the renewals of whole building assets

The method developed in the current research provides a time interval for the best intervention for the renewals of whole building assets. A new approach may be researched incorporating the interventions with the total cost (combined with operational costs, routine costs, renewal costs etc.) incurred during the planned period. The previous solutions of time intervals combined with the minimum cost will define a specific time for interventions. The study will require practical involvement with local councils to observe actual cost patterns and analyse the time point at which the minimum cost occurs.

- Aggregation of sustainability index values to other levels of the element hierarchy

The current study derives the sustainability index for building components which represent the lowest level of the element hierarchy. This is the detailed approach but some councils may prefer specific approaches. Therefore it is necessary to find sustainability index values for top levels (component type, component group). The average value is the usual method in this regard but the application has not been proven methodically. Hence, supported by research, a consistent approach can be designed by future researchers.

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APPENDIX A: NAMS BUILDING HIERACHY (IPWEA, 2009)

Component Group	Component Type	Component
Electrical Services	Distribution Boards	Distribution Boards
		Local DBS
		Main Fuse box
		Main Switch Board
		Mechanical Services Switch Board
		Meter Boxes
	Emergency Lighting (Not fire related)	Batteries
		Controller / Cabling
		Lamps
	Emergency Power	Fuel Tank
		Gen Set - alternator
		Gen Set - engine
	Lighting - External/Internal	Controller / Cabling
		Down Lights
		Exit Signs
		Fittings
		Fluorescent Lights
		Incandescent Lights
		Lamps
	Lighting - Flood / Security	Controller / Cabling
		Fittings
		Lamps
		Local Security Lighting
		Pole Top Lights (External)
	Misc.	Light Switches & Power points
	Power Conditioning	Batteries
		Chargers
		UPS
	Power Conversion	Power conversion
Exterior Works	Buildings	Carport
		Covered Ways
		Garage
		Shed (Garden / Tool Shed)
		Sun Screen/Awning
		Verandah - Roof Only
	Channels	Channels & Grating

		Kerb & Channelling
	Civil works	Block Wall
		Brick Wall
		Retaining Walls (Concrete)
		Retaining Walls (Timber)
	Fencing	Corrugated Iron Fence
		Fence - Paint Finish
		Picket Fence
		Post & Rail Fence
		Post & Wire Fence
		Post / Rail / Mesh Fence
		Steel Security fence
		Timber Paling Fence
		Wire Mesh Fence
	Furniture	Park Seat
		Picnic Table
		Rubbish Bin
	Gates	Metal Gate
		Motorised Sliding Gate
		Steel/Mesh Gate
		Timber Gate
		Wrought Iron Gate
	Hard stand	Asphalt /Sealed Areas
		Asphalt Paths
		Astro Turf
		Carpark Marking
		Cobblestone
		Concrete Paths / Ramps
		Concrete Paver / Interlocking Blocks
		Concrete Slab
		Timber Kerbs
	Misc.	Decking
		Paint
		Shade Cloth
	Signs	Sign (Exterior)
		Sign (Route)
		Sign (Timber)
	Stairs & rails	Handrail Metal
		Handrail Timber
		Staircase - Metal
		Staircase - Timber
	Water tanks	Water Tank - Concrete
		Water Tank - Metal
		Water Tank – Plastic

External Fabric	External Walls	Brick Cladding
		Curtain Walling (Glass)
		Fibrolite Sheeting
		Hardiplank
		Marble
		Metal Cladding
		Paint Finish
		Plaster
		Plywood
		Precast Concrete Wall Panels
		Pvc Weatherboards
		Shiplap
		Weatherboard - Timber
	Roof	Butynol Roofing
		Colorbond
		Compressed Fibre
		Concrete Roof Slabs
		Downpipes - Metal
		Downpipes - Pvc
		Glass
		Metal Roofing
		Paint Finish
		Safety access system - anchor points
		Safety access system - walkways
		Shingles - Timber
		Skylight
		Soffits - Fibrolite
		Soffits - Timber
		Spouting - Metal
		Spouting - Pvc
		Tile Roofing - Clay
		Tile Roofing - Concrete
		Tile Roofing - Slate
		Timber Fascia
		Translucent Sheeting
	Windows & Doors	Alum Frame Glass - Dble Door
		Alum Frame Glass - Sgle Door
		Alum/Glass - Sliding Dble Door
		Alum/Glass - Sliding Sgle Door
		Aluminium Windows
		Automatic Opening Doors
		Door Hardware (Handles/Locks)
		Emergency Exit Door - Double
		Emergency Exit Door - Single
		Glass Door
		Louvre Windows
		Metal Clad Doors

		Metal Framed Windows
		Metal Roller Doors
		Paint Finish
		Roller Doors
		Sliding Doors
		Timber / Glass Door
		Timber Entrance Door
		Timber Framed Windows
Fire Services	**Fire Alarm System**	Cabling
		Fire / mimic panels
		Heat detectors
		Magnetic door holders
		Smoke detectors
	Fire Communications	EWIS panel
	Fire Services	Fire Extinguishers
		Fire Hose Reels
		Ventilating Fans
	Fire Sprinkler System	Pipes and valves
		Sprinkler heads
	Hydrant System	Hydrant System
Interior Finishes	**Ceiling Finishes**	Fibrolite
		Gyprock Lining
		Hardboard
		Insulation
		Paint Finish
		Particle Board
		Plaster Finish
		Prefinished Metal
		Softboard / Pinex Tiles / Lining
		Suspended Panel (incl Frame)
		Suspended Panel (incl Frame), Acoustic
		Suspended Panel (incl Frame), Plasterboard
		Timber Lining
	Fixtures & Fittings	Dishwasher
		Fixed Desks, Tables, Seating
		Fixed Seating
		Grabrails
		Hand dryer
		Handrail Stainless
		Holland Blinds

		Joinery Fttgs - Built-In
		Kitchen Bench and Joinery
		Kitchen Bench S/S
		Mirror
		Paint Finish
		Shelving
		Stoves
		Towel rail
		Work Benches
		Zip Heater
	Floor Finishes	Carpet
		Ceramic Tiles
		Cork
		Epoxy
		Floating Timber
		Floor - Particle Board
		Floor - Timber T & G
		Paint Finish
		Parquet
		Polyurethane Finish
		Rubber
		Stair Nosing
		Vinyl
	Interior Doors	Accordion / Folding
		Alum/ Safety glass
		Alum/ Toughened glass
		Doors - Hollow-Core
		Doors - Solid
		Fire Doors
		Glass
		Metal Doors
		Metal Roller Door
		Paint Finish (Per Leaf)
		Polyurethane Finish (Per Leaf)
		Safety glass
		Sliding Doors
		Solid Core
		Solid Core/ Glass
		Solid Core/ Safety glass
		Swing Doors - (Pair) (Smoke Stop)
		Timber Glass
	Interior Walls	Int Window - Metal
		Int Window - Timber
		Proprietary
	Interior Windows	Alum/ Glass
		Alum/ Safety glass

		Lead glass
		Safety glass
	Wall Finishes	Fibrolite
		Glass
		Gyprock Lining
		Hardboard
		Melteca / Seratone
		Paint Finish
		Particle Board
		Plaster Finish
		Plywood
		Prefinished Metal
		Stainless steel
		Tiles - Ceramic
		Timber Lining
		Vinyl
		Wallpaper Finish
Lifts / Hoist Services	Vertical Transport	Car Interior & buttons
		Car Structure
		Door sets
		Lift controller
		Motor / Gears
Mechanical Services	Air Distribution	Ducting
		Fire & Smoke Dampers
		Hepa Filters
		Supply Fans
		Variable Air Volume
	Air Handling Units	AHU - Motor
		AHU Structure
		Duct Heaters
		Motorised valves
		Variable Speed Drives
	Building Management System	Cabling / mech / elect
		Computer /printer
		Controller / hard drive
	Chilled Water System	Chiller - Compressor
		Chiller Structure
		Pipework
		Pumps
		Valves
	Compressed Air/Pneumatics	Controller / Cabling
		Dryers
		Engine
		Pipe work

		Pneumatic valve actuators
	Condenser Water System	Condensing Unit
		Cooling tower - infills
		Cooling tower - structure
		Fans/Motors
		Pipework
		Pumps
		Valves
		Water tank
	Fan Coil Units	Fan Coil Unit
	Heating System	Boiler - gas fired
		Burner
		Hot Water Cylinder
		Hot water pumps
		Pipework
		Space Heaters
		Underflr/Wall &/Or Ceiling Heat.
		Valves
	HVAC Control System	HVAC Control System
	Split A/C Units	Split A/C Units
	Ventilation System	Axial Ventillation Fans
		Centrifugal Ventilation Fans
		Exhaust Fan
		Ventilation System
Plumbing	Sanitary Plumbing	Back Flow Valve
		Bath
		Handbasin
		Laundry Tub
		Safety Shower and Eyewash unit
		Shower Unit (Acrylic 3 Sided)
		Tap
		Toilet - China Bowl /Cistern
		Toilet - S/S Urinal
		Toilet Bowl & Cistern
		Urinal
		Vanity (Incl Basin)
Security Services	Access Control Systems	Cabling
		Card readers / Keypad
		Controller Computer/badge printer etc
	CCTV Systems	Cabling
		Cameras
		Controller / hard drive

		Monitors
	Intruder/Duress Alarm System	Cabling
		Controller / hard drive
		Monitors
		Sensors
	Special Services	Barrier Arms
		Card Reader
		CCTV Camera / Monitor
		Elect. Security Sys. - Domestic
		Generators (Standby)
Water Services	Domestic Cold Water	Dosing
		Tanks- Pipes
		Valves
	Domestic Hot Water	Circulation Pumps
		Tanks- Pipes
		Treament
		Valves
		Water Cylinder
	Warm Water	Dosing
		HWS systems/controls
		Pipes and valves
		Pumps

APPENDIX B: INDUSTRY-WIDE QUESTIONNAIRE 1

Questionnaire

This questionnaire aims to explore the potential impacts associated with the maintenance and renewal activities of community buildings. As per literature review and preliminary discussion with experts from local councils, the potential impacts can be categorized into four aspects, i.e. environmental, social, economic and functional impacts. The questionnaire mainly consists of two sections; Section A and Section B.

The questionnaire survey forms part of a research project titled "A Reliability Based Approach for Sustainable Management of Community Buildings" funded by Australian Research Council. This project is undertaken by a team of researchers at RMIT University, in collaboration with six local councils in Victoria. Your feedback and timely response will greatly assist with the conduct of this research project.

Please be assured that the information obtained from this survey will be kept strictly confidential and will only be used for research purposes. (Please go through the plain language form for further understanding of the research and researchers' obligations).

Section A : Demographic Data (The responses do not influence your anonymity...

Please give your details according to the following questions.

*1. Respondent Current Position:

*2. How long have you been working in the current position:

*3. Number of buildings under management of the council:

*4. Please insert the state in Australia where your organisation is located:

*5. Total years of work experience in building management:

Section B: Survey on Impacts

This section explores potential impacts that maintenance and renewal activities of community buildings may bring to the community and end users in four aspects, i.e.

1 Environmental impact
2 Economic impact
3 Social impact
4 Functional impact

Environmental Impact

Environmental impacts refer to the influences that maintenance and renewal activities of community buildings may bring to or potentially affect the environment. Other environmental factors that may influence the maintenance and renewal are also considered in this section.

***1. Please indicate your view in using following indicators to measure the environmental impact. (For example if you consider 'Reduction of GHG emission' as a major indicator to be included for environmental impact, please tick on your selection of 'Strongly Agree')**

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Reduction of GHG (Green House Gas) emission					
Amount of noise pollution					
Amount of air pollution					
The amount of green energy consumption					
The amount of energy consumption					
The amount of used materials with low embodied energy					
Impact on energy use					
Lighting efficiency					
Sourcing materials locally					
Building reuse					
Cyclist facilities					
Use of rain water					
Recycling of grey water					
Impact on quality storm water run-off					
Impact on portable water use					
Thermal comfort					
Indoor air quality					
Impact on air quality					
Usage of hazardous goods and materials (e.g. asbestos)					
Refurbishment of noise & pollution					
Usage of recycled materials					
Construction waste management					

Operation waste management	○	○	○	○	○

2. If there are indicators missing from the above list, please add them below.

1.

2.

3.

Economic Impact

Economic impacts refer to the influences that maintenance and renewal activities of community buildings may bring to or potentially affect the economy of local community. Other economic/financial factors that may influence the maintenance and renewal are also considered in this section.

***1. Please indicate your view in using following indicators to measure the economic impact. (For example if you consider 'Additional capital investment cost' as a major indicator to be included for economic impact, please tick on your selection of 'Strongly Agree')**

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Additional capital investment cost	○	○	○	○	○
Maintenance and renewal cost	○	○	○	○	○
Replacement cost	○	○	○	○	○
Operation cost	○	○	○	○	○
Residual value including land value	○	○	○	○	○
Routine maintenance cost	○	○	○	○	○
Local employment opportunity	○	○	○	○	○
Use of local materials and local suppliers	○	○	○	○	○
Revenue generation for the council	○	○	○	○	○
Community land value (Depending on the current market value)	○	○	○	○	○
small business advancement in the local government area	○	○	○	○	○
Tourism significance	○	○	○	○	○
Minimising life cycle costs	○	○	○	○	○

2. If there are indicators missing from the above list, please add them below.

1.

2.

3.

Social Impact

Social impacts refer to the influences that maintenance and renewal activities of community buildings may bring to or potentially affect the equity,welfare, culture, health & safety of local community. Other social factors that may influence the maintenance and renewal are also considered in this section.

***1. Please indicate your agreement in using following indicators to measure the social impact? (For example if you consider 'Provision of recreational and essential facilities' as a major indicator to be included for social impact, please put a tick on your selection either 'Agree' or 'Strongly Agree' as preferable according to the importance)**

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Equity of employees	○	○	○	○	○
Equity of users	○	○	○	○	○
Provision of recreational and essential facilities	○	○	○	○	○
Accessibility	○	○	○	○	○
Community's health/well-being (The hygienic condition)	○	○	○	○	○
Feeling of security	○	○	○	○	○
Impact on healthy life style	○	○	○	○	○
Usage of hazardous goods and materials	○	○	○	○	○
Heritage value of the building	○	○	○	○	○
Image of the council	○	○	○	○	○
Aesthetics	○	○	○	○	○
Local community involved	○	○	○	○	○
Local community expectation	○	○	○	○	○
Local community support	○	○	○	○	○
Level of community demand	○	○	○	○	○
Number of community members that will benefit	○	○	○	○	○
Proximity via public transport, cycling, walking	○	○	○	○	○

2. If there are indicators missing from the above list, please add them below.

1.

2.

3.

Functional Impact

Functional impacts refer to the influences that maintenance and renewal activities of community buildings may bring to or potentially affect the functioning of those buildings. Other functional factors that may influence the maintenance and renewal are also considered in this section.

***1. Please indicate your agreement in using following indicators to measure the functional impact? (For example if you consider 'Number of users affected due to failure' as a major indicator to be included for functional impact, please put a 'X' in front of the indicator & under the column 'Agree' or 'Strongly Agree' as preferable according to the importance)**

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Number of users affected due to failure	○	○	○	○	○
Severity of failure	○	○	○	○	○
Length of interruption to service	○	○	○	○	○
Availability of alternative resources	○	○	○	○	○
Adaptability of users to a proposed change	○	○	○	○	○
Likelihood of failure	○	○	○	○	○
Facilities and services management	○	○	○	○	○
Minimum acceptable level of service	○	○	○	○	○
Accountability to users	○	○	○	○	○
The ability to meet short term demands	○	○	○	○	○
The ability to meet long term demands	○	○	○	○	○
Compliance to the Building Code	○	○	○	○	○
Compliance to the OHS standards	○	○	○	○	○
Compliance to disability	○	○	○	○	○

2. If there are indicators missing from the above list, please add them below.

1.

2.

3.

Survey Outcome

1. Would you like to have a summary of the research findings from this survey?

◯ Yes ◯ No

2. Would you like to participate in another survey related to this research?

◯ Yes ◯ No

Thank you for completing this survey. The time and effort that you have spent, is greatly appreciated.

APPENDIX C: INDUSTRY-WIDE QUESTIONNAIRE 2

Assessment of factors influenced on the Sustainable Management of Community Buildings

Introduction of the questionnaire

In our research, we have identified that the sustainable management of community buildings is mainly influenced by factors from four aspects including Environmental aspect, Economic aspect, Social aspect and Functional aspect. Also the research has finalized, based on analysis of responses to a previous questionnaire, that each aforementioned aspect of sustainable management of community buildings is governed by several criteria; such as seven (7) criteria for environmental aspect, four (4) criteria for economic aspect, four (4) criteria for social aspect and three (3) criteria for functional aspect. All criteria related to each aspect are shown in the following;

Environmental Aspect
- Water quality and management
- Material sustainability
- Energy efficiency
- Waste management
- Air and noise pollution
- User comfort
- Usage of Hazardous goods and materials

Economic Aspect
- Life cycle cost
- Land value
- Local economy
- Additional capital investment

Social Aspect
- Local community engagement
- Community benefits and equity
- Neighbourhood character
- Employee well-being

Functional Aspect
- Impact of failure and response
- Level of service
- Compliance to building standards and regulations

This questionnaire aims to assess the realtive importance of:

Assessment of factors influenced on the Sustainable Management of Community Buildings

- each aspect
- each attribute criterion of environmental aspect
- each attribute criterion of economic aspect
- each attribute criterion of social aspect
- each attribute criterion of functional aspect

Your expertise and knowledge on the management of community buildings is highly appreciated and your participation in this questinnaire is critical to the success of this research project.

Please be assured that the information obtained from this survey will be kept strictly confidential and will only be used for research purposes.

Also please be kind enough to duly return this questionnaire responded by 26th of April 2012.

Assessment of factors influenced on the Sustainable Management of Community Buildings

Section A: Demographic Data

***1. Please state the current position of your job?**

***2. How long have you been working in the current position?**

***3. Please state the number of buildings currently managed by the council?**

***4. In what state is your organisation located?**

***5. Please state your total years of work experience in the discipline of building management?**

Assessment of factors influenced on the Sustainable Management of Community Buildings

Section B: Assessment of relative importance of major aspects

Firstly, in question 6, you are requested to rank the major aspects (Environmental aspect, Economic aspect, Social aspect and Functional aspect) according to the relative importance for the sustainable management of community buildings. (e.g. rank 1 represents the highest important aspect and rank 4 represents the lowest important aspect)

***6. Please rank the following major aspects according to the importance of sustainable management of community buildings**

	Rank 1	Rank 2	Rank 3	Rank 4
Environmental Aspect	○	○	○	○
Economic Aspect	○	○	○	○
Social Aspect	○	○	○	○
Functional Aspect	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Secondly, in question 7, we need to further assess the realtive importance of those aspects by comparing them in pair wise. The importance is classified in the following descending order;

• Absolute importance: The first aspect is absolutely important than the second aspect for the sustainable management of community buildings (this is greater than very strong importance)

• Very Strong importance: The first aspect is very stronger in importance than the second aspect for the sustainable management of community buildings (this is greater than strong importance)

• Strong importance: The first aspect is stronger in importance than the second aspect for the sustainable management of community buildings (this is greater than moderate importance)

• Moderate importance: The first aspect is moderately important than the second aspect for the sustainable management of community buildings (this is greater than equal importance)

• Equal importance: Two aspects are equally important for the sustainable management of community buildings

• Moderate least importance: The first aspect is moderately least important than the second aspect (or the second aspect is moderately important than the first aspect) for the sustainable management of community buildings (this is less than equal importance)

• Strong least importance: The first aspect is least stronger in importance than the second aspect (or the second aspect is stronger in importance than the first aspect) for the sustainable management of community buildings (this is less than moderate least importance)

•Very Strong least importance: The first aspect is very stronger in least importance than the second aspect (or the second aspect is very stronger in importance than the first aspect) for the sustainable management of community buildings (this is less than strong least importance)

• Absolute least importance: The first aspect is absolutely least important than the second aspect (or the second aspect is absolutely important than the first aspect) for the sustainable management of community buildings (this is less than very strong least importance)

Assessment of factors influenced on the Sustainable Management of Community Buildings

***7. Please give your rating on the relative importance of the first aspect compared to the second aspect (Please maintain your responses consistent with your previous ranking results)**

	Absolute Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate Least Importance	Strong Least Importance	Very Strong Least Importance	Absolute Least Importance
Environmental aspect Vs Economic aspect	○	○	○	○	○	○	○	○	○
Environmental aspect Vs Social aspect	○	○	○	○	○	○	○	○	○
Environmental aspect Vs Functional aspect	○	○	○	○	○	○	○	○	○
Economic aspect Vs Social aspect	○	○	○	○	○	○	○	○	○
Economic aspect Vs Functional aspect	○	○	○	○	○	○	○	○	○
Social aspect Vs Functional aspect	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Section C: Assessment of importance of the criteria under environmental asp...

The research has analyzed seven criteria under environmental aspect as influencing to the sustainable management of community buildings. They are;

- Water quality and management
- Material sustainability
- Energy efficiency
- Waste management
- Air and noise pollution
- User comfort
- Usage of hazardous goods and materials

As in the previous section, firstly, in question 8, you are requested to rank those criteria according to the importance of the sustainable management of community buildings from the perspective of environmental aspect e.g. rank 1 represents the highest important criterion and rank 7 represents the lowest important criterion.

***8. Please rank the following criteria under environmental aspect according to the importance of the sustainable management of community buildings from the perspective of environmental aspect**

	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7
Water quality and management	○	○	○	○	○	○	○
Material sustainability	○	○	○	○	○	○	○
Energy efficiency	○	○	○	○	○	○	○
Waste management	○	○	○	○	○	○	○
Air and noise pollution	○	○	○	○	○	○	○
User Comfort	○	○	○	○	○	○	○
Usage of hazardous goods and materials	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Secondly, in question 9, we need to further assess the importance of those criteria by considering them in pair wise. The importance is classified in the following descending order;

• Absolute importance: The first criterion is absolutely important than the second criterion for the sustainable management of community buildings from the perspective of environmental aspect (this is greater than very strong importance)

• Very Strong importance: The first criterion is very stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of environmental aspect (this is greater than strong importance)

• Strong importance: The first criterion is stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of environmental aspect (this is greater than moderate importance)

• Moderate importance: The first criterion is moderately important than the second criterion for the sustainable management of community buildings from the perspective of environmental aspect (this is greater than equal importance)

• Equal importance: Two criteria are equally important for the sustainable management of community buildings from the perspective of environmental aspect

• Moderate least importance: The first criterion is moderately least important than the second criterion (or the second criterion is moderately important than the first criteria) for the sustainable management of community buildings from the perspective of environmental aspect (this is less than equal importance)

• Strong least importance: The first criterion is least stronger in importance than the second criterion (or the second criterion is stronger in importance than the first criteria) for the sustainable management of community buildings from the perspective of environmental aspect (this is less than moderate least importance)

• Very Strong least importance: The first criterion is very stronger in least importance than the second criterion (or the second criterion is very stronger in importance than the first criterion) for the sustainable management of community buildings from the perspective of environmental aspect (this is less than strong least importance)

• Absolute least importance: The first criterion is absolutely least important than the second criterion (or the second criterion is absolutely important than the first criteria) for the sustainable management of community buildings from the perspective of environmental aspect (this is less than very strong least importance)

Assessment of factors influenced on the Sustainable Management of Community Buildings

***9. Please give your rating on the relative importance of the first criterion compared to the second criterion (Please maintain your responses consistent with your previous ranking results)**

	Absolute Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate Least Importance	Strong Least Importance	Very Strong Least Importance	Absolute Least Importance
Water quality and management Vs Material sustainability	○	○	○	○	○	○	○	○	○
Water quality and management Vs Energy efficiency	○	○	○	○	○	○	○	○	○
Water quality and management Vs Waste management	○	○	○	○	○	○	○	○	○
Water quality and management Vs Air and noise pollution	○	○	○	○	○	○	○	○	○
Water quality and management Vs User comfort	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Water quality and management Vs Usage of hazardous goods and materials	○	○	○	○	○	○	○	○	○
Material sustainability Vs Energy efficiency	○	○	○	○	○	○	○	○	○
Material sustainability Vs Waste management	○	○	○	○	○	○	○	○	○
Material sustainability Vs Air and noise pollution	○	○	○	○	○	○	○	○	○
Material sustainability Vs User comfort	○	○	○	○	○	○	○	○	○
Material sustainability Vs Usage of hazardous goods and materials	○	○	○	○	○	○	○	○	○
Energy efficiency Vs	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Waste management									
Energy efficiency Vs Air and noise pollution	○	○	○	○	○	○	○	○	○
Energy efficiency Vs User comfort	○	○	○	○	○	○	○	○	○
Energy efficiency Vs Usage of hazardous goods and materials	○	○	○	○	○	○	○	○	○
Waste management Vs Air and noise pollution	○	○	○	○	○	○	○	○	○
Waste management Vs User comfort	○	○	○	○	○	○	○	○	○
Waste management Vs Usage of hazardous goods and materials	○	○	○	○	○	○	○	○	○
Air and noise pollution Vs	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

User comfort									
Air and noise pollution Vs Usage of hazardous goods and materials	○	○	○	○	○	○	○	○	○
User comfort Vs Usage of hazardous goods and materials	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Section D: Assessment of importance of the criteria under economic aspect

The research has analyzed four criteria under economic aspect as influencing to the sustainable management of community buildings. They are;

- Life cycle cost
- Land value
- Local economy
- Additional capital investment

As in the previous section, firstly, in question 10, you are requested to rank those criteria according to the importance of the sustainable management of community buildings from the perspective of economic aspect. (e.g. Rank 1 represents the highest important criterion and Rank 4 represents the lowest important criterion)

***10. Please rank the following criteria under economic aspect according to the importance of sustainable management of community buildings from the perspective of economic aspect**

	Rank 1	Rank 2	Rank 3	Rank 4
Life cycle cost	○	○	○	○
Land value	○	○	○	○
Local economy	○	○	○	○
Additional capital investment	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Secondly, in question 11, we need to further assess the importance of those criteria by considering them in pair wise. The importance is classified in the following descending order;

• Absolute importance: The first criterion is absolutely important than the second criterion for the sustainable management of community buildings from the perspective of economic aspect (this is greater than very strong importance)

• Very Strong importance: The first criterion is very stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of economic aspect (this is greater than strong importance)

• Strong importance: The first criterion is stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of economic aspect (this is greater than moderate importance)

• Moderate importance: The first criterion is moderately important than the second criterion for the sustainable management of community buildings from the perspective of economic aspect (this is greater than equal importance)

• Equal importance: Two criteria are equally important for the sustainable management of community buildings from the perspective of economic aspect

• Moderate least importance: The first criterion is moderately least important than the second criterion (or the second criterion is moderately important than the first criteria) for the sustainable management of community buildings from the perspective of economic aspect (this is less than equal importance)

• Strong least importance: The first criterion is least stronger in importance than the second criterion (or the second criterion is stronger in importance than the first criteria) for the sustainable management of community buildings from the perspective of economic aspect (this is less than moderate least importance)

• Very Strong least importance: The first criterion is very stronger in least importance than the second criterion (or the second criterion is very stronger in importance than the first criterion) for the sustainable management of community buildings from the perspective of economic aspect (this is less than strong least importance)

• Absolute least importance: The first criterion is absolutely least important than the second criterion (or the second criterion is absolutely important than the first criteria) for the sustainable management of community buildings from the perspective of economic aspect (this is less than very strong least importance)

Assessment of factors influenced on the Sustainable Management of Community Buildings

***11. Please give your rating on the relative importance of the first criterion compared to the second criterion (Please maintain your responses consistent with your previous ranking results)**

	Absolute Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate Least Importance	Strong Least Importance	Very Strong Least Importance	Absolute Least Importance
Life cycle cost Vs Land value	○	○	○	○	○	○	○	○	○
Life cycle cost Vs Local economy	○	○	○	○	○	○	○	○	○
Life cycle cost Vs Additional capital investment	○	○	○	○	○	○	○	○	○
Land value Vs Local economy	○	○	○	○	○	○	○	○	○
Land value Vs Additional capital investment	○	○	○	○	○	○	○	○	○
Local economy Vs Additional capital investment	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Section E: Assessment of importance of the criteria under social aspect

The research has analyzed four criteria under social aspect as influencing to the sustainable management of community buildings. They are;

- Local community engagement
- Community benefits and equity
- neighbourhood character
- Employee well-being

As in the previous section, firstly, in question 12, you are requested to rank those attribute criteria according to the importance of the sustainable management of community buildings from the perspective of social aspect. (e.g. Rank 1 represents the highest important criterion and Rank 4 represents the lowest important criterion)

***12. Please rank the following attribute criteria under social aspect according to the importance of sustainable management of community buildings from the perspective of social aspect**

	Rank 1	Rank 2	Rank 3	Rank 4
Local community engagement	○	○	○	○
Community benefits and equity	○	○	○	○
Neighbourhood character	○	○	○	○
Employee well-being	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Secondly, in question 13, we need to further assess the importance of those criteria by considering them in pair wise. The importance is classified in the following descending order;

• Absolute importance: The first criterion is absolutely important than the second criterion for the sustainable management of community buildings from the perspective of social aspect (this is greater than very strong importance)

• Very Strong importance: The first criterion is very stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of social aspect (this is greater than strong importance)

• Strong importance: The first criterion is stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of social aspect (this is greater than moderate importance)

• Moderate importance: The first criterion is moderately important than the second criterion for the sustainable management of community buildings from the perspective of social aspect (this is greater than equal importance)

• Equal importance: Two criteria are equally important for the sustainable management of community buildings from the perspective of social aspect

• Moderate least importance: The first criterion is moderately least important than the second criterion (or the second criterion is moderately important than the first criteria) for the sustainable management of community buildings from the perspective of social aspect (this is less than equal importance)

• Strong least importance: The first criterion is least stronger in importance than the second criterion (or the second criterion is stronger in importance than the first criteria) for the sustainable management of community buildings from the perspective of social aspect (this is less than moderate least importance)

• Very Strong least importance: The first criterion is very stronger in least importance than the second criterion (or the second criterion is very stronger in importance than the first criterion) for the sustainable management of community buildings from the perspective of social aspect (this is less than strong least importance)

• Absolute least importance: The first criterion is absolutely least important than the second criterion (or the second criterion is absolutely important than the first criteria) for the sustainable management of community buildings from the perspective of social aspect (this is less than very strong least importance)

Assessment of factors influenced on the Sustainable Management of Community Buildings

***13. Please give your rating on the relative importance of the first criterion compared to the second criterion (Please maintain your responses consistent with your previous ranking results)**

	Absolute Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate Least Importance	Strong Least Importance	Very Strong Least Importance	Absolute Least Importance
Local community engagement Vs Community benefits and equity	○	○	○	○	○	○	○	○	○
Local community engagement Vs Neighbourhood character	○	○	○	○	○	○	○	○	○
Local community engagement Vs Employee well-being	○	○	○	○	○	○	○	○	○
Community benefits and equity Vs Neighbourhood character	○	○	○	○	○	○	○	○	○
Community benefits and equity Vs Employee well-being	○	○	○	○	○	○	○	○	○
Neighbourhood character Vs Employee well-being	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Section F: Assessment of importance of the criteria under functional aspect

The research has analyzed three criteria under functional aspect as influencing to the sustainable management of community buildings. They are;

- Impact of failure and response
- Level of service
- Compliance to building standards and regulations

As in the previous section, firstly, in question 14, you are requested to rank those criteria according to the importance of the sustainable management of community buildings from the perspective of functional aspect. (e.g. Rank 1 represents the highest important criterion and rank 4 represents the lowest important criterion)

***14. Please rank the following criteria under functional aspect according to the importance of sustainable management of community buildings from the perspective of functional aspect**

	Rank 1	Rank 2	Rank 3
Impact of failure and response	○	○	○
Level of service	○	○	○
Compliance to building standards and regulations	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Secondly, in question 15, we need to further assess the importance of those criteria by considering them in pair wise. The importance is classified in the following descending order;

- Absolute importance: The first criterion is absolutely important than the second criterion for the sustainable management of community buildings from the perspective of functional aspect (this is greater than very strong importance)

- Very Strong importance: The first criterion is very stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of functional aspect (this is greater than strong importance)

- Strong importance: The first criterion is stronger in importance than the second criterion for the sustainable management of community buildings from the perspective of functional aspect (this is greater than moderate importance)

- Moderate importance: The first criterion is moderately important than the second criterion for the sustainable management of community buildings from the perspective of functional aspect (this is greater than equal importance)

- Equal importance: Two criteria are equally important for the sustainable management of community buildings from the perspective of functional aspect

- Moderate least importance: The first criterion is moderately least important than the second criterion (or the second criterion is moderately important than the first criteria) for the sustainable management of community buildings from the perspective of functional aspect (this is less than equal importance)

- Strong least importance: The first criterion is least stronger in importance than the second criterion (or the second criterion is stronger in importance than the first criteria) for the sustainable management of community buildings from the perspective of functional aspect (this is less than moderate least importance)

- Very Strong least importance: The first criterion is very stronger in least importance than the second criterion (or the second criterion is very stronger in importance than the first criterion) for the sustainable management of community buildings from the perspective of functional aspect (this is less than strong least importance)

- Absolute least importance: The first criterion is absolutely least important than the second criterion (or the second criterion is absolutely important than the first criteria) for the sustainable management of community buildings from the perspective of functional aspect (this is less than very strong least importance)

Assessment of factors influenced on the Sustainable Management of Community Buildings

***15. Please give your rating on the relative importance of the first criterion compared to the second criterion (Please maintain your responses consistent with your previous ranking results)**

	Absolute Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate Least Importance	Strong Least Importance	Very Strong Least Importance	Absolute Least Importance
Impact of failure and response Vs Level of service	○	○	○	○	○	○	○	○	○
Impact of failure and response Vs Compliance to building standards and regulations	○	○	○	○	○	○	○	○	○
Level of service Vs Compliance to building standards and regulations	○	○	○	○	○	○	○	○	○

Assessment of factors influenced on the Sustainable Management of Community Buildings

Conclusion of the survey

Thank you for completing this questionnaire. The time and effort that you have spent is greatly appreciated.

APPENDIX D: RULE BLOCK

Rule Number	Input Variables					Output Variable
	Functional Impact (0.18)	Environmental Impact (0.37)	Economic Impact (0.27)	Social Impact (0.18)	DOS	Sustainability Index
1	Very High	Very High	Very High	Very High	1.00	Very High
2	Very High	Very High	Very High	Low	0.82	Very High
3	Very High	Very High	Very High	Medium	0.82	Very High
4	Very High	Very High	Very High	High	0.82	Very High
5	Very High	Very High	Very High	Very Low	0.82	Very High
6	Very High	Very High	Low	Very High	0.73	Very High
7	Very High	Very High	Medium	Very High	0.73	Very High
8	Very High	Very High	High	Very High	0.73	Very High
9	Very High	Very High	Very Low	Very High	0.73	Very High
10	Low	Very High	Very High	Very High	0.82	Very High
11	Medium	Very High	Very High	Very High	0.82	Very High
12	High	Very High	Very High	Very High	0.82	Very High
13	Very Low	Very High	Very High	Very High	0.82	Very High
14	Very High	Low	Very High	Very High	0.63	Very High
15	Very High	Medium	Very High	Very High	0.63	Very High
16	Very High	High	Very High	Very High	0.63	Very High
17	Very High	Very Low	Very High	Very High	0.63	Very High
18	Very High	Very High	Low	Medium	0.55	Very High
19	Very High	Very High	Low	High	0.55	Very High
20	Very High	Very High	Low	Very Low	0.55	Very High
21	Very High	Very High	Medium	Low	0.55	Very High
22	Very High	Very High	Medium	High	0.55	Very High
23	Very High	Very High	Medium	Very Low	0.55	Very High
24	Very High	Very High	High	Low	0.55	Very High
25	Very High	Very High	High	Medium	0.55	Very High
26	Very High	Very High	High	Very Low	0.55	Very High
27	Very High	Very High	Very Low	Low	0.55	Very High
28	Very High	Very High	Very Low	Medium	0.55	Very High
29	Very High	Very High	Very Low	High	0.55	Very High
30	Very High	Very High	Low	Low	0.55	Very High
31	Very High	Very High	Medium	Medium	0.55	Very High
32	Very High	Very High	High	High	0.55	Very High
33	Very High	Very High	Very Low	Very Low	0.55	Very High
34	Very High	Low	Very High	Medium	0.45	Very High
35	Very High	Low	Very High	High	0.45	Very High
36	Very High	Low	Very High	Very Low	0.45	Very High
37	Very High	Medium	Very High	Low	0.45	Very High
38	Very High	Medium	Very High	High	0.45	Very High
39	Very High	Medium	Very High	Very Low	0.45	Very High
40	Very High	High	Very High	Low	0.45	Very High
41	Very High	High	Very High	Medium	0.45	Very High
42	Very High	High	Very High	Very Low	0.45	Very High
43	Very High	Very Low	Very High	Low	0.45	Very High

44	Very High	Very Low	Very High	Medium	0.45	Very High
45	Very High	Very Low	Very High	High	0.45	Very High
46	Very High	Low	Very High	Low	0.45	Very High
47	Very High	Medium	Very High	Medium	0.45	Very High
48	Very High	High	Very High	High	0.45	Very High
49	Very High	Very Low	Very High	Very Low	0.45	Very High
50	Very High	Low	Medium	Very High	0.36	Very High
51	Very High	Low	High	Very High	0.36	Very High
52	Very High	Low	Very Low	Very High	0.36	Very High
53	Very High	Medium	Low	Very High	0.36	Very High
54	Very High	Medium	High	Very High	0.36	Very High
55	Very High	Medium	Very Low	Very High	0.36	Very High
56	Very High	High	Low	Very High	0.36	Very High
57	Very High	High	Medium	Very High	0.36	Very High
58	Very High	High	Very Low	Very High	0.36	Very High
59	Very High	Very Low	Low	Very High	0.36	Very High
60	Very High	Very Low	Medium	Very High	0.36	Very High
61	Very High	Very Low	High	Very High	0.36	Very High
62	Very High	Low	Low	Very High	0.36	Very High
63	Very High	Medium	Medium	Very High	0.36	Very High
64	Very High	High	High	Very High	0.36	Very High
65	Very High	Very Low	Very Low	Very High	0.36	Very High
66	Low	Very High	Very High	Medium	0.64	Very High
67	Low	Very High	Very High	High	0.64	Very High
68	Low	Very High	Very High	Very Low	0.64	Very High
69	Medium	Very High	Very High	Low	0.64	Very High
70	Medium	Very High	Very High	High	0.64	Very High
71	Medium	Very High	Very High	Very Low	0.64	Very High
72	High	Very High	Very High	Low	0.64	Very High
73	High	Very High	Very High	Medium	0.64	Very High
74	High	Very High	Very High	Very Low	0.64	Very High
75	Very Low	Very High	Very High	Low	0.64	Very High
76	Very Low	Very High	Very High	Medium	0.64	Very High
77	Very Low	Very High	Very High	High	0.64	Very High
78	Low	Very High	Very High	Low	0.64	Very High
79	Medium	Very High	Very High	Medium	0.64	Very High
80	High	Very High	Very High	High	0.64	Very High
81	Very Low	Very High	Very High	Very Low	0.64	Very High
82	Low	Very High	Medium	Very High	0.55	Very High
83	Low	Very High	High	Very High	0.55	Very High
84	Low	Very High	Very Low	Very High	0.55	Very High
85	Medium	Very High	Low	Very High	0.55	Very High
86	Medium	Very High	High	Very High	0.55	Very High
87	Medium	Very High	Very Low	Very High	0.55	Very High
88	High	Very High	Low	Very High	0.55	Very High
89	High	Very High	Medium	Very High	0.55	Very High
90	High	Very High	Very Low	Very High	0.55	Very High
91	Very Low	Very High	Low	Very High	0.55	Very High
92	Very Low	Very High	Medium	Very High	0.55	Very High

93	Very Low	Very High	High	Very High	0.55	Very High
94	Low	Very High	Low	Very High	0.55	Very High
95	Medium	Very High	Medium	Very High	0.55	Very High
96	High	Very High	High	Very High	0.55	Very High
97	Very Low	Very High	Very Low	Very High	0.55	Very High
98	Low	Medium	Very High	Very High	0.45	Very High
99	Low	High	Very High	Very High	0.45	Very High
100	Low	Very Low	Very High	Very High	0.45	Very High
101	Medium	Low	Very High	Very High	0.45	Very High
102	Medium	High	Very High	Very High	0.45	Very High
103	Medium	Very Low	Very High	Very High	0.45	Very High
104	High	Low	Very High	Very High	0.45	Very High
105	High	Medium	Very High	Very High	0.45	Very High
106	High	Very Low	Very High	Very High	0.45	Very High
107	Very Low	Low	Very High	Very High	0.45	Very High
108	Very Low	Medium	Very High	Very High	0.45	Very High
109	Very Low	High	Very High	Very High	0.45	Very High
110	Low	Low	Very High	Very High	0.45	Very High
111	Medium	Medium	Very High	Very High	0.45	Very High
112	High	High	Very High	Very High	0.45	Very High
113	Very Low	Very Low	Very High	Very High	0.45	Very High
114	Very High	Low	Medium	High	0.18	Very High
115	Very High	Low	Medium	Very Low	0.18	Very High
116	Very High	Low	High	Medium	0.18	Very High
117	Very High	Low	High	Very Low	0.18	Very High
118	Very High	Low	Very Low	Medium	0.18	Very High
119	Very High	Low	Very Low	High	0.18	Very High
120	Very High	Medium	Low	High	0.18	Very High
121	Very High	Medium	Low	Very Low	0.18	Very High
122	Very High	Medium	High	Low	0.18	Very High
123	Very High	Medium	High	Very Low	0.18	Very High
124	Very High	Medium	Very Low	Low	0.18	Very High
125	Very High	Medium	Very Low	High	0.18	Very High
126	Very High	High	Low	Medium	0.18	Very High
127	Very High	High	Low	Very Low	0.18	Very High
128	Very High	High	Medium	Low	0.18	Very High
129	Very High	High	Medium	Very Low	0.18	Very High
130	Very High	High	Very Low	Low	0.18	Very High
131	Very High	High	Very Low	Medium	0.18	Very High
132	Very High	Very Low	Low	Medium	0.18	Very High
133	Very High	Very Low	Low	High	0.18	Very High
134	Very High	Very Low	Medium	Low	0.18	Very High
135	Very High	Very Low	Medium	High	0.18	Very High
136	Very High	Very Low	High	Low	0.18	Very High
137	Very High	Very Low	High	Medium	0.18	Very High
138	Very High	Low	Low	Medium	0.18	Very High
139	Very High	Low	Low	High	0.18	Very High
140	Very High	Low	Low	Very Low	0.18	Very High
141	Very High	Low	Medium	Low	0.18	Very High

142	Very High	Low	High	Low	0.18	Very High
143	Very High	Low	Very Low	Low	0.18	Very High
144	Very High	Medium	Low	Low	0.18	Very High
145	Very High	High	Low	Low	0.18	Very High
146	Very High	Very Low	Low	Low	0.18	Very High
147	Very High	Medium	Medium	Low	0.18	Very High
148	Very High	Medium	Medium	High	0.18	Very High
149	Very High	Medium	Medium	Very Low	0.18	Very High
150	Very High	Medium	Low	Medium	0.18	Very High
151	Very High	Medium	High	Medium	0.18	Very High
152	Very High	Medium	Very Low	Medium	0.18	Very High
153	Very High	Low	Medium	Medium	0.18	Very High
154	Very High	High	Medium	Medium	0.18	Very High
155	Very High	Very Low	Medium	Medium	0.18	Very High
156	Very High	High	High	Low	0.18	Very High
157	Very High	High	High	Medium	0.18	Very High
158	Very High	High	High	Very Low	0.18	Very High
159	Very High	High	Low	High	0.18	Very High
160	Very High	High	Medium	High	0.18	Very High
161	Very High	High	Very Low	High	0.18	Very High
162	Very High	Low	High	High	0.18	Very High
163	Very High	Medium	High	High	0.18	Very High
164	Very High	Very Low	High	High	0.18	Very High
165	Very High	Very Low	Very Low	Low	0.18	Very High
166	Very High	Very Low	Very Low	Medium	0.18	Very High
167	Very High	Very Low	Very Low	High	0.18	Very High
168	Very High	Very Low	Low	Very Low	0.18	Very High
169	Very High	Very Low	Medium	Very Low	0.18	Very High
170	Very High	Very Low	High	Very Low	0.18	Very High
171	Very High	Low	Very Low	Very Low	0.18	Very High
172	Very High	Medium	Very Low	Very Low	0.18	Very High
173	Very High	High	Very Low	Very Low	0.18	Very High
174	Very High	Low	Low	Low	0.18	Very High
175	Very High	Medium	Medium	Medium	0.18	Very High
176	Very High	High	High	High	0.18	Very High
177	Very High	Very Low	Very Low	Very Low	0.18	Very High
178	Low	Very High	Medium	High	0.37	Very High
179	Low	Very High	Medium	Very Low	0.37	Very High
180	Low	Very High	High	Medium	0.37	Very High
181	Low	Very High	High	Very Low	0.37	Very High
182	Low	Very High	Very Low	Medium	0.37	Very High
183	Low	Very High	Very Low	High	0.37	Very High
184	Medium	Very High	Low	High	0.37	Very High
185	Medium	Very High	Low	Very Low	0.37	Very High
186	Medium	Very High	High	Low	0.37	Very High
187	Medium	Very High	High	Very Low	0.37	Very High
188	Medium	Very High	Very Low	Low	0.37	Very High
189	Medium	Very High	Very Low	High	0.37	Very High
190	High	Very High	Low	Medium	0.37	Very High

191	High	Very High	Low	Very Low	0.37	Very High
192	High	Very High	Medium	Low	0.37	Very High
193	High	Very High	Medium	Very Low	0.37	Very High
194	High	Very High	Very Low	Low	0.37	Very High
195	High	Very High	Very Low	Medium	0.37	Very High
196	Very Low	Very High	Low	Medium	0.37	Very High
197	Very Low	Very High	Low	High	0.37	Very High
198	Very Low	Very High	Medium	Low	0.37	Very High
199	Very Low	Very High	Medium	High	0.37	Very High
200	Very Low	Very High	High	Low	0.37	Very High
201	Very Low	Very High	High	Medium	0.37	Very High
202	Low	Very High	Low	Medium	0.37	Very High
203	Low	Very High	Low	High	0.37	Very High
204	Low	Very High	Low	Very Low	0.37	Very High
205	Low	Very High	Medium	Low	0.37	Very High
206	Low	Very High	High	Low	0.37	Very High
207	Low	Very High	Very Low	Low	0.37	Very High
208	Medium	Very High	Low	Low	0.37	Very High
209	High	Very High	Low	Low	0.37	Very High
210	Very Low	Very High	Low	Low	0.37	Very High
211	Medium	Very High	Medium	Low	0.37	Very High
212	Medium	Very High	Medium	High	0.37	Very High
213	Medium	Very High	Medium	Very Low	0.37	Very High
214	Medium	Very High	Low	Medium	0.37	Very High
215	Medium	Very High	High	Medium	0.37	Very High
216	Medium	Very High	Very Low	Medium	0.37	Very High
217	Low	Very High	Medium	Medium	0.37	Very High
218	High	Very High	Medium	Medium	0.37	Very High
219	Very Low	Very High	Medium	Medium	0.37	Very High
220	High	Very High	High	Low	0.37	Very High
221	High	Very High	High	Medium	0.37	Very High
222	High	Very High	High	Very Low	0.37	Very High
223	High	Very High	Low	High	0.37	Very High
224	High	Very High	Medium	High	0.37	Very High
225	High	Very High	Very Low	High	0.37	Very High
226	Low	Very High	High	High	0.37	Very High
227	Medium	Very High	High	High	0.37	Very High
228	Very Low	Very High	High	High	0.37	Very High
229	Very Low	Very High	Very Low	Low	0.37	Very High
230	Very Low	Very High	Very Low	Medium	0.37	Very High
231	Very Low	Very High	Very Low	High	0.37	Very High
232	Very Low	Very High	Low	Very Low	0.37	Very High
233	Very Low	Very High	Medium	Very Low	0.37	Very High
234	Very Low	Very High	High	Very Low	0.37	Very High
235	Low	Very High	Very Low	Very Low	0.37	Very High
236	Medium	Very High	Very Low	Very Low	0.37	Very High
237	High	Very High	Very Low	Very Low	0.37	Very High
238	Low	Very High	Low	Low	0.37	Very High
239	Medium	Very High	Medium	Medium	0.37	Very High

240	High	Very High	High	High	0.37	Very High
241	Very Low	Very High	Very Low	Very Low	0.37	Very High
242	Low	Medium	Very High	High	0.27	Very High
243	Low	Medium	Very High	Very Low	0.27	Very High
244	Low	High	Very High	Medium	0.27	Very High
245	Low	High	Very High	Very Low	0.27	Very High
246	Low	Very Low	Very High	Medium	0.27	Very High
247	Low	Very Low	Very High	High	0.27	Very High
248	Medium	Low	Very High	High	0.27	Very High
249	Medium	Low	Very High	Very Low	0.27	Very High
250	Medium	High	Very High	Low	0.27	Very High
251	Medium	High	Very High	Very Low	0.27	Very High
252	Medium	Very Low	Very High	Low	0.27	Very High
253	Medium	Very Low	Very High	High	0.27	Very High
254	High	Low	Very High	Medium	0.27	Very High
255	High	Low	Very High	Very Low	0.27	Very High
256	High	Medium	Very High	Low	0.27	Very High
257	High	Medium	Very High	Very Low	0.27	Very High
258	High	Very Low	Very High	Low	0.27	Very High
259	High	Very Low	Very High	Medium	0.27	Very High
260	Very Low	Low	Very High	Medium	0.27	Very High
261	Very Low	Low	Very High	High	0.27	Very High
262	Very Low	Medium	Very High	Low	0.27	Very High
263	Very Low	Medium	Very High	High	0.27	Very High
264	Very Low	High	Very High	Low	0.27	Very High
265	Very Low	High	Very High	Medium	0.27	Very High
266	Low	Low	Very High	Medium	0.27	Very High
267	Low	Low	Very High	High	0.27	Very High
268	Low	Low	Very High	Very Low	0.27	Very High
269	Low	Medium	Very High	Low	0.27	Very High
270	Low	High	Very High	Low	0.27	Very High
271	Low	Very Low	Very High	Low	0.27	Very High
272	Medium	Low	Very High	Low	0.27	Very High
273	High	Low	Very High	Low	0.27	Very High
274	Very Low	Low	Very High	Low	0.27	Very High
275	Medium	Medium	Very High	Low	0.27	Very High
276	Medium	Medium	Very High	High	0.27	Very High
277	Medium	Medium	Very High	Very Low	0.27	Very High
278	Medium	Low	Very High	Medium	0.27	Very High
279	Medium	High	Very High	Medium	0.27	Very High
280	Medium	Very Low	Very High	Medium	0.27	Very High
281	Low	Medium	Very High	Medium	0.27	Very High
282	High	Medium	Very High	Medium	0.27	Very High
283	Very Low	Medium	Very High	Medium	0.27	Very High
284	High	High	Very High	Low	0.27	Very High
285	High	High	Very High	Medium	0.27	Very High
286	High	High	Very High	Very Low	0.27	Very High
287	High	Low	Very High	High	0.27	Very High
288	High	Medium	Very High	High	0.27	Very High

289	High	Very Low	Very High	High	0.27	Very High
290	Low	High	Very High	High	0.27	Very High
291	Medium	High	Very High	High	0.27	Very High
292	Very Low	High	Very High	High	0.27	Very High
293	Very Low	Very Low	Very High	Low	0.27	Very High
294	Very Low	Very Low	Very High	Medium	0.27	Very High
295	Very Low	Very Low	Very High	High	0.27	Very High
296	Very Low	Low	Very High	Very Low	0.27	Very High
297	Very Low	Medium	Very High	Very Low	0.27	Very High
298	Very Low	High	Very High	Very Low	0.27	Very High
299	Low	Very Low	Very High	Very Low	0.27	Very High
300	Medium	Very Low	Very High	Very Low	0.27	Very High
301	High	Very Low	Very High	Very Low	0.27	Very High
302	Low	Low	Very High	Low	0.27	Very High
303	Medium	Medium	Very High	Medium	0.27	Very High
304	High	High	Very High	High	0.27	Very High
305	Very Low	Very Low	Very High	Very Low	0.27	Very High
306	Low	Medium	High	Very High	0.18	Very High
307	Low	Medium	Very Low	Very High	0.18	Very High
308	Low	High	Medium	Very High	0.18	Very High
309	Low	High	Very Low	Very High	0.18	Very High
310	Low	Very Low	Medium	Very High	0.18	Very High
311	Low	Very Low	High	Very High	0.18	Very High
312	Medium	Low	High	Very High	0.18	Very High
313	Medium	Low	Very Low	Very High	0.18	Very High
314	Medium	High	Low	Very High	0.18	Very High
315	Medium	High	Very Low	Very High	0.18	Very High
316	Medium	Very Low	Low	Very High	0.18	Very High
317	Medium	Very Low	High	Very High	0.18	Very High
318	High	Low	Medium	Very High	0.18	Very High
319	High	Low	Very Low	Very High	0.18	Very High
320	High	Medium	Low	Very High	0.18	Very High
321	High	Medium	Very Low	Very High	0.18	Very High
322	High	Very Low	Low	Very High	0.18	Very High
323	High	Very Low	Medium	Very High	0.18	Very High
324	Very Low	Low	Medium	Very High	0.18	Very High
325	Very Low	Low	High	Very High	0.18	Very High
326	Very Low	Medium	Low	Very High	0.18	Very High
327	Very Low	Medium	High	Very High	0.18	Very High
328	Very Low	High	Low	Very High	0.18	Very High
329	Very Low	High	Medium	Very High	0.18	Very High
330	Low	Low	Medium	Very High	0.18	Very High
331	Low	Low	High	Very High	0.18	Very High
332	Low	Low	Very Low	Very High	0.18	Very High
333	Low	Medium	Low	Very High	0.18	Very High
334	Low	High	Low	Very High	0.18	Very High
335	Low	Very Low	Low	Very High	0.18	Very High
336	Medium	Low	Low	Very High	0.18	Very High
337	High	Low	Low	Very High	0.18	Very High

338	Very Low	Low	Low	Very High	0.18	Very High
339	Medium	Medium	Low	Very High	0.18	Very High
340	Medium	Medium	High	Very High	0.18	Very High
341	Medium	Medium	Very Low	Very High	0.18	Very High
342	Medium	Low	Medium	Very High	0.18	Very High
343	Medium	High	Medium	Very High	0.18	Very High
344	Medium	Very Low	Medium	Very High	0.18	Very High
345	Low	Medium	Medium	Very High	0.18	Very High
346	High	Medium	Medium	Very High	0.18	Very High
347	Very Low	Medium	Medium	Very High	0.18	Very High
348	High	High	Low	Very High	0.18	Very High
349	High	High	Medium	Very High	0.18	Very High
350	High	High	Very Low	Very High	0.18	Very High
351	High	Low	High	Very High	0.18	Very High
352	High	Medium	High	Very High	0.18	Very High
353	High	Very Low	High	Very High	0.18	Very High
354	Low	High	High	Very High	0.18	Very High
355	Medium	High	High	Very High	0.18	Very High
356	Very Low	High	High	Very High	0.18	Very High
357	Very Low	Very Low	Low	Very High	0.18	Very High
358	Very Low	Very Low	Medium	Very High	0.18	Very High
359	Very Low	Very Low	High	Very High	0.18	Very High
360	Very Low	Low	Very Low	Very High	0.18	Very High
361	Very Low	Medium	Very Low	Very High	0.18	Very High
362	Very Low	High	Very Low	Very High	0.18	Very High
363	Low	Very Low	Very Low	Very High	0.18	Very High
364	Medium	Very Low	Very Low	Very High	0.18	Very High
365	High	Very Low	Very Low	Very High	0.18	Very High
366	Low	Low	Low	Very High	0.18	Very High
367	Medium	Medium	Medium	Very High	0.18	Very High
368	High	High	High	Very High	0.18	Very High
369	Very Low	Very Low	Very Low	Very High	0.18	Very High
370	Very High	Very High	Very High	Very High	1.00	High
371	Very High	Very High	Very High	Very High	0.82	High
372	Very High	Very High	Very High	Very High	0.82	High
373	Very High	Very High	Very High	Very High	0.82	High
374	Very High	Very High	Very High	Very High	0.82	High
375	Very High	Very High	Very High	Very High	0.73	High
376	Very High	Very High	Very High	Very High	0.73	High
377	Very High	Very High	Very High	Very High	0.73	High
378	Very High	Very High	Very High	Very High	0.73	High
379	Very High	Very High	Very High	Very High	0.82	High
380	Very High	Very High	Very High	Very High	0.82	High
381	Very High	Very High	Very High	Very High	0.82	High
382	Very High	Very High	Very High	Very High	0.82	High
383	Very High	Very High	Very High	Very High	0.63	High
384	Very High	Very High	Very High	Very High	0.63	High
385	Very High	Very High	Very High	Very High	0.63	High
386	Very High	Very High	Very High	Very High	0.63	High

387	Very High	Very High	Very High	Very High	0.55	High
388	Very High	Very High	Very High	Very High	0.55	High
389	Very High	Very High	Very High	Very High	0.55	High
390	Very High	Very High	Very High	Very High	0.55	High
391	Very High	Very High	Very High	Very High	0.55	High
392	Very High	Very High	Very High	Very High	0.55	High
393	Very High	Very High	Very High	Very High	0.55	High
394	Very High	Very High	Very High	Very High	0.55	High
395	Very High	Very High	Very High	Very High	0.55	High
396	Very High	Very High	Very High	Very High	0.55	High
397	Very High	Very High	Very High	Very High	0.55	High
398	Very High	Very High	Very High	Very High	0.55	High
399	Very High	Very High	Very High	Very High	0.55	High
400	Very High	Very High	Very High	Very High	0.55	High
401	Very High	Very High	Very High	Very High	0.55	High
402	Very High	Very High	Very High	Very High	0.55	High
403	Very High	Very High	Very High	Very High	0.45	High
404	Very High	Very High	Very High	Very High	0.45	High
405	Very High	Very High	Very High	Very High	0.45	High
406	Very High	Very High	Very High	Very High	0.45	High
407	Very High	Very High	Very High	Very High	0.45	High
408	Very High	Very High	Very High	Very High	0.45	High
409	Very High	Very High	Very High	Very High	0.45	High
410	Very High	Very High	Very High	Very High	0.45	High
411	Very High	Very High	Very High	Very High	0.45	High
412	Very High	Very High	Very High	Very High	0.45	High
413	Very High	Very High	Very High	Very High	0.45	High
414	Very High	Very High	Very High	Very High	0.45	High
415	Very High	Very High	Very High	Very High	0.45	High
416	Very High	Very High	Very High	Very High	0.45	High
417	Very High	Very High	Very High	Very High	0.45	High
418	Very High	Very High	Very High	Very High	0.45	High
419	Very High	Very High	Very High	Very High	0.36	High
420	Very High	Very High	Very High	Very High	0.36	High
421	Very High	Very High	Very High	Very High	0.36	High
422	Very High	Very High	Very High	Very High	0.36	High
423	Very High	Very High	Very High	Very High	0.36	High
424	Very High	Very High	Very High	Very High	0.36	High
425	Very High	Very High	Very High	Very High	0.36	High
426	Very High	Very High	Very High	Very High	0.36	High
427	Very High	Very High	Very High	Very High	0.36	High
428	Very High	Very High	Very High	Very High	0.36	High
429	Very High	Very High	Very High	Very High	0.36	High
430	Very High	Very High	Very High	Very High	0.36	High
431	Very High	Very High	Very High	Very High	0.36	High
432	Very High	Very High	Very High	Very High	0.36	High
433	Very High	Very High	Very High	Very High	0.36	High
434	Very High	Very High	Very High	Very High	0.36	High
435	Very High	Very High	Very High	Very High	0.64	High

436	Very High	Very High	Very High	Very High	0.64	High
437	Very High	Very High	Very High	Very High	0.64	High
438	Very High	Very High	Very High	Very High	0.64	High
439	Very High	Very High	Very High	Very High	0.64	High
440	Very High	Very High	Very High	Very High	0.64	High
441	Very High	Very High	Very High	Very High	0.64	High
442	Very High	Very High	Very High	Very High	0.64	High
443	Very High	Very High	Very High	Very High	0.64	High
444	Very High	Very High	Very High	Very High	0.64	High
445	Very High	Very High	Very High	Very High	0.64	High
446	Very High	Very High	Very High	Very High	0.64	High
447	Very High	Very High	Very High	Very High	0.64	High
448	Very High	Very High	Very High	Very High	0.64	High
449	Very High	Very High	Very High	Very High	0.64	High
450	Very High	Very High	Very High	Very High	0.64	High
451	Very High	Very High	Very High	Very High	0.55	High
452	Very High	Very High	Very High	Very High	0.55	High
453	Very High	Very High	Very High	Very High	0.55	High
454	Very High	Very High	Very High	Very High	0.55	High
455	Very High	Very High	Very High	Very High	0.55	High
456	Very High	Very High	Very High	Very High	0.55	High
457	Very High	Very High	Very High	Very High	0.55	High
458	Very High	Very High	Very High	Very High	0.55	High
459	Very High	Very High	Very High	Very High	0.55	High
460	Very High	Very High	Very High	Very High	0.55	High
461	Very High	Very High	Very High	Very High	0.55	High
462	Very High	Very High	Very High	Very High	0.55	High
463	Very High	Very High	Very High	Very High	0.55	High
464	Very High	Very High	Very High	Very High	0.55	High
465	Very High	Very High	Very High	Very High	0.55	High
466	Very High	Very High	Very High	Very High	0.55	High
467	Very High	Very High	Very High	Very High	0.45	High
468	Very High	Very High	Very High	Very High	0.45	High
469	Very High	Very High	Very High	Very High	0.45	High
470	Very High	Very High	Very High	Very High	0.45	High
471	Very High	Very High	Very High	Very High	0.45	High
472	Very High	Very High	Very High	Very High	0.45	High
473	Very High	Very High	Very High	Very High	0.45	High
474	Very High	Very High	Very High	Very High	0.45	High
475	Very High	Very High	Very High	Very High	0.45	High
476	Very High	Very High	Very High	Very High	0.45	High
477	Very High	Very High	Very High	Very High	0.45	High
478	Very High	Very High	Very High	Very High	0.45	High
479	Very High	Very High	Very High	Very High	0.45	High
480	Very High	Very High	Very High	Very High	0.45	High
481	Very High	Very High	Very High	Very High	0.45	High
482	Very High	Very High	Very High	Very High	0.45	High
483	Very High	Very High	Very High	Very High	0.18	High
484	Very High	Very High	Very High	Very High	0.18	High

485	Very High	Very High	Very High	Very High	0.18	High
486	Very High	Very High	Very High	Very High	0.18	High
487	Very High	Very High	Very High	Very High	0.18	High
488	Very High	Very High	Very High	Very High	0.18	High
489	Very High	Very High	Very High	Very High	0.18	High
490	Very High	Very High	Very High	Very High	0.18	High
491	Very High	Very High	Very High	Very High	0.18	High
492	Very High	Very High	Very High	Very High	0.18	High
493	Very High	Very High	Very High	Very High	0.18	High
494	Very High	Very High	Very High	Very High	0.18	High
495	Very High	Very High	Very High	Very High	0.18	High
496	Very High	Very High	Very High	Very High	0.18	High
497	Very High	Very High	Very High	Very High	0.18	High
498	Very High	Very High	Very High	Very High	0.18	High
499	Very High	Very High	Very High	Very High	0.18	High
500	Very High	Very High	Very High	Very High	0.18	High
501	Very High	Very High	Very High	Very High	0.18	High
502	Very High	Very High	Very High	Very High	0.18	High
503	Very High	Very High	Very High	Very High	0.18	High
504	Very High	Very High	Very High	Very High	0.18	High
505	Very High	Very High	Very High	Very High	0.18	High
506	Very High	Very High	Very High	Very High	0.18	High
507	Very High	Very High	Very High	Very High	0.18	High
508	Very High	Very High	Very High	Very High	0.18	High
509	Very High	Very High	Very High	Very High	0.18	High
510	Very High	Very High	Very High	Very High	0.18	High
511	Very High	Very High	Very High	Very High	0.18	High
512	Very High	Very High	Very High	Very High	0.18	High
513	Very High	Very High	Very High	Very High	0.18	High
514	Very High	Very High	Very High	Very High	0.18	High
515	Very High	Very High	Very High	Very High	0.18	High
516	Very High	Very High	Very High	Very High	0.18	High
517	Very High	Very High	Very High	Very High	0.18	High
518	Very High	Very High	Very High	Very High	0.18	High
519	Very High	Very High	Very High	Very High	0.18	High
520	Very High	Very High	Very High	Very High	0.18	High
521	Very High	Very High	Very High	Very High	0.18	High
522	Very High	Very High	Very High	Very High	0.18	High
523	Very High	Very High	Very High	Very High	0.18	High
524	Very High	Very High	Very High	Very High	0.18	High
525	Very High	Very High	Very High	Very High	0.18	High
526	Very High	Very High	Very High	Very High	0.18	High
527	Very High	Very High	Very High	Very High	0.18	High
528	Very High	Very High	Very High	Very High	0.18	High
529	Very High	Very High	Very High	Very High	0.18	High
530	Very High	Very High	Very High	Very High	0.18	High
531	Very High	Very High	Very High	Very High	0.18	High
532	Very High	Very High	Very High	Very High	0.18	High
533	Very High	Very High	Very High	Very High	0.18	High

534	Very High	Very High	Very High	Very High	0.18	High
535	Very High	Very High	Very High	Very High	0.18	High
536	Very High	Very High	Very High	Very High	0.18	High
537	Very High	Very High	Very High	Very High	0.18	High
538	Very High	Very High	Very High	Very High	0.18	High
539	Very High	Very High	Very High	Very High	0.18	High
540	Very High	Very High	Very High	Very High	0.18	High
541	Very High	Very High	Very High	Very High	0.18	High
542	Very High	Very High	Very High	Very High	0.18	High
543	Very High	Very High	Very High	Very High	0.18	High
544	Very High	Very High	Very High	Very High	0.18	High
545	Very High	Very High	Very High	Very High	0.18	High
546	Very High	Very High	Very High	Very High	0.18	High
547	Very High	Very High	Very High	Very High	0.37	High
548	Very High	Very High	Very High	Very High	0.37	High
549	Very High	Very High	Very High	Very High	0.37	High
550	Very High	Very High	Very High	Very High	0.37	High
551	Very High	Very High	Very High	Very High	0.37	High
552	Very High	Very High	Very High	Very High	0.37	High
553	Very High	Very High	Very High	Very High	0.37	High
554	Very High	Very High	Very High	Very High	0.37	High
555	Very High	Very High	Very High	Very High	0.37	High
556	Very High	Very High	Very High	Very High	0.37	High
557	Very High	Very High	Very High	Very High	0.37	High
558	Very High	Very High	Very High	Very High	0.37	High
559	Very High	Very High	Very High	Very High	0.37	High
560	Very High	Very High	Very High	Very High	0.37	High
561	Very High	Very High	Very High	Very High	0.37	High
562	Very High	Very High	Very High	Very High	0.37	High
563	Very High	Very High	Very High	Very High	0.37	High
564	Very High	Very High	Very High	Very High	0.37	High
565	Very High	Very High	Very High	Very High	0.37	High
566	Very High	Very High	Very High	Very High	0.37	High
567	Very High	Very High	Very High	Very High	0.37	High
568	Very High	Very High	Very High	Very High	0.37	High
569	Very High	Very High	Very High	Very High	0.37	High
570	Very High	Very High	Very High	Very High	0.37	High
571	Very High	Very High	Very High	Very High	0.37	High
572	Very High	Very High	Very High	Very High	0.37	High
573	Very High	Very High	Very High	Very High	0.37	High
574	Very High	Very High	Very High	Very High	0.37	High
575	Very High	Very High	Very High	Very High	0.37	High
576	Very High	Very High	Very High	Very High	0.37	High
577	Very High	Very High	Very High	Very High	0.37	High
578	Very High	Very High	Very High	Very High	0.37	High
579	Very High	Very High	Very High	Very High	0.37	High
580	Very High	Very High	Very High	Very High	0.37	High
581	Very High	Very High	Very High	Very High	0.37	High
582	Very High	Very High	Very High	Very High	0.37	High

583	Very High	Very High	Very High	Very High	0.37	High
584	Very High	Very High	Very High	Very High	0.37	High
585	Very High	Very High	Very High	Very High	0.37	High
586	Very High	Very High	Very High	Very High	0.37	High
587	Very High	Very High	Very High	Very High	0.37	High
588	Very High	Very High	Very High	Very High	0.37	High
589	Very High	Very High	Very High	Very High	0.37	High
590	Very High	Very High	Very High	Very High	0.37	High
591	Very High	Very High	Very High	Very High	0.37	High
592	Very High	Very High	Very High	Very High	0.37	High
593	Very High	Very High	Very High	Very High	0.37	High
594	Very High	Very High	Very High	Very High	0.37	High
595	Very High	Very High	Very High	Very High	0.37	High
596	Very High	Very High	Very High	Very High	0.37	High
597	Very High	Very High	Very High	Very High	0.37	High
598	Very High	Very High	Very High	Very High	0.37	High
599	Very High	Very High	Very High	Very High	0.37	High
600	Very High	Very High	Very High	Very High	0.37	High
601	Very High	Very High	Very High	Very High	0.37	High
602	Very High	Very High	Very High	Very High	0.37	High
603	Very High	Very High	Very High	Very High	0.37	High
604	Very High	Very High	Very High	Very High	0.37	High
605	Very High	Very High	Very High	Very High	0.37	High
606	Very High	Very High	Very High	Very High	0.37	High
607	Very High	Very High	Very High	Very High	0.37	High
608	Very High	Very High	Very High	Very High	0.37	High
609	Very High	Very High	Very High	Very High	0.37	High
610	Very High	Very High	Very High	Very High	0.37	High
611	Very High	Very High	Very High	Very High	0.27	High
612	Very High	Very High	Very High	Very High	0.27	High
613	Very High	Very High	Very High	Very High	0.27	High
614	Very High	Very High	Very High	Very High	0.27	High
615	Very High	Very High	Very High	Very High	0.27	High
616	Very High	Very High	Very High	Very High	0.27	High
617	Very High	Very High	Very High	Very High	0.27	High
618	Very High	Very High	Very High	Very High	0.27	High
619	Very High	Very High	Very High	Very High	0.27	High
620	Very High	Very High	Very High	Very High	0.27	High
621	Very High	Very High	Very High	Very High	0.27	High
622	Very High	Very High	Very High	Very High	0.27	High
623	Very High	Very High	Very High	Very High	0.27	High
624	Very High	Very High	Very High	Very High	0.27	High
625	Very High	Very High	Very High	Very High	0.27	High
626	Very High	Very High	Very High	Very High	0.27	High
627	Very High	Very High	Very High	Very High	0.27	High
628	Very High	Very High	Very High	Very High	0.27	High
629	Very High	Very High	Very High	Very High	0.27	High
630	Very High	Very High	Very High	Very High	0.27	High
631	Very High	Very High	Very High	Very High	0.27	High

632	Very High	Very High	Very High	Very High	0.27	High
633	Very High	Very High	Very High	Very High	0.27	High
634	Very High	Very High	Very High	Very High	0.27	High
635	Very High	Very High	Very High	Very High	0.27	High
636	Very High	Very High	Very High	Very High	0.27	High
637	Very High	Very High	Very High	Very High	0.27	High
638	Very High	Very High	Very High	Very High	0.27	High
639	Very High	Very High	Very High	Very High	0.27	High
640	Very High	Very High	Very High	Very High	0.27	High
641	Very High	Very High	Very High	Very High	0.27	High
642	Very High	Very High	Very High	Very High	0.27	High
643	Very High	Very High	Very High	Very High	0.27	High
644	Very High	Very High	Very High	Very High	0.27	High
645	Very High	Very High	Very High	Very High	0.27	High
646	Very High	Very High	Very High	Very High	0.27	High
647	Very High	Very High	Very High	Very High	0.27	High
648	Very High	Very High	Very High	Very High	0.27	High
649	Very High	Very High	Very High	Very High	0.27	High
650	Very High	Very High	Very High	Very High	0.27	High
651	Very High	Very High	Very High	Very High	0.27	High
652	Very High	Very High	Very High	Very High	0.27	High
653	Very High	Very High	Very High	Very High	0.27	High
654	Very High	Very High	Very High	Very High	0.27	High
655	Very High	Very High	Very High	Very High	0.27	High
656	Very High	Very High	Very High	Very High	0.27	High
657	Very High	Very High	Very High	Very High	0.27	High
658	Very High	Very High	Very High	Very High	0.27	High
659	Very High	Very High	Very High	Very High	0.27	High
660	Very High	Very High	Very High	Very High	0.27	High
661	Very High	Very High	Very High	Very High	0.27	High
662	Very High	Very High	Very High	Very High	0.27	High
663	Very High	Very High	Very High	Very High	0.27	High
664	Very High	Very High	Very High	Very High	0.27	High
665	Very High	Very High	Very High	Very High	0.27	High
666	Very High	Very High	Very High	Very High	0.27	High
667	Very High	Very High	Very High	Very High	0.27	High
668	Very High	Very High	Very High	Very High	0.27	High
669	Very High	Very High	Very High	Very High	0.27	High
670	Very High	Very High	Very High	Very High	0.27	High
671	Very High	Very High	Very High	Very High	0.27	High
672	Very High	Very High	Very High	Very High	0.27	High
673	Very High	Very High	Very High	Very High	0.27	High
674	Very High	Very High	Very High	Very High	0.27	High
675	Very High	Very High	Very High	Very High	0.18	High
676	Very High	Very High	Very High	Very High	0.18	High
677	Very High	Very High	Very High	Very High	0.18	High
678	Very High	Very High	Very High	Very High	0.18	High
679	Very High	Very High	Very High	Very High	0.18	High
680	Very High	Very High	Very High	Very High	0.18	High

681	Very High	Very High	Very High	Very High	0.18	High
682	Very High	Very High	Very High	Very High	0.18	High
683	Very High	Very High	Very High	Very High	0.18	High
684	Very High	Very High	Very High	Very High	0.18	High
685	Very High	Very High	Very High	Very High	0.18	High
686	Very High	Very High	Very High	Very High	0.18	High
687	Very High	Very High	Very High	Very High	0.18	High
688	Very High	Very High	Very High	Very High	0.18	High
689	Very High	Very High	Very High	Very High	0.18	High
690	Very High	Very High	Very High	Very High	0.18	High
691	Very High	Very High	Very High	Very High	0.18	High
692	Very High	Very High	Very High	Very High	0.18	High
693	Very High	Very High	Very High	Very High	0.18	High
694	Very High	Very High	Very High	Very High	0.18	High
695	Very High	Very High	Very High	Very High	0.18	High
696	Very High	Very High	Very High	Very High	0.18	High
697	Very High	Very High	Very High	Very High	0.18	High
698	Very High	Very High	Very High	Very High	0.18	High
699	Very High	Very High	Very High	Very High	0.18	High
700	Very High	Very High	Very High	Very High	0.18	High
701	Very High	Very High	Very High	Very High	0.18	High
702	Very High	Very High	Very High	Very High	0.18	High
703	Very High	Very High	Very High	Very High	0.18	High
704	Very High	Very High	Very High	Very High	0.18	High
705	Very High	Very High	Very High	Very High	0.18	High
706	Very High	Very High	Very High	Very High	0.18	High
707	Very High	Very High	Very High	Very High	0.18	High
708	Very High	Very High	Very High	Very High	0.18	High
709	Very High	Very High	Very High	Very High	0.18	High
710	Very High	Very High	Very High	Very High	0.18	High
711	Very High	Very High	Very High	Very High	0.18	High
712	Very High	Very High	Very High	Very High	0.18	High
713	Very High	Very High	Very High	Very High	0.18	High
714	Very High	Very High	Very High	Very High	0.18	High
715	Very High	Very High	Very High	Very High	0.18	High
716	Very High	Very High	Very High	Very High	0.18	High
717	Very High	Very High	Very High	Very High	0.18	High
718	Very High	Very High	Very High	Very High	0.18	High
719	Very High	Very High	Very High	Very High	0.18	High
720	Very High	Very High	Very High	Very High	0.18	High
721	Very High	Very High	Very High	Very High	0.18	High
722	Very High	Very High	Very High	Very High	0.18	High
723	Very High	Very High	Very High	Very High	0.18	High
724	Very High	Very High	Very High	Very High	0.18	High
725	Very High	Very High	Very High	Very High	0.18	High
726	Very High	Very High	Very High	Very High	0.18	High
727	Very High	Very High	Very High	Very High	0.18	High
728	Very High	Very High	Very High	Very High	0.18	High
729	Very High	Very High	Very High	Very High	0.18	High

730	Very High	Very High	Very High	Very High	0.18	High
731	Very High	Very High	Very High	Very High	0.18	High
732	Very High	Very High	Very High	Very High	0.18	High
733	Very High	Very High	Very High	Very High	0.18	High
734	Very High	Very High	Very High	Very High	0.18	High
735	Very High	Very High	Very High	Very High	0.18	High
736	Very High	Very High	Very High	Very High	0.18	High
737	Very High	Very High	Very High	Very High	0.18	High
738	Very High	Very High	Very High	Very High	0.18	High
739	Very High	Very High	Very High	Very High	1.00	Medium
740	Very High	Very High	Very High	Very High	0.82	Medium
741	Very High	Very High	Very High	Very High	0.82	Medium
742	Very High	Very High	Very High	Very High	0.82	Medium
743	Very High	Very High	Very High	Very High	0.82	Medium
744	Very High	Very High	Very High	Very High	0.73	Medium
745	Very High	Very High	Very High	Very High	0.73	Medium
746	Very High	Very High	Very High	Very High	0.73	Medium
747	Very High	Very High	Very High	Very High	0.73	Medium
748	Very High	Very High	Very High	Very High	0.82	Medium
749	Very High	Very High	Very High	Very High	0.82	Medium
750	Very High	Very High	Very High	Very High	0.82	Medium
751	Very High	Very High	Very High	Very High	0.82	Medium
752	Very High	Very High	Very High	Very High	0.63	Medium
753	Very High	Very High	Very High	Very High	0.63	Medium
754	Very High	Very High	Very High	Very High	0.63	Medium
755	Very High	Very High	Very High	Very High	0.63	Medium
756	Very High	Very High	Very High	Very High	0.55	Medium
757	Very High	Very High	Very High	Very High	0.55	Medium
758	Very High	Very High	Very High	Very High	0.55	Medium
759	Very High	Very High	Very High	Very High	0.55	Medium
760	Very High	Very High	Very High	Very High	0.55	Medium
761	Very High	Very High	Very High	Very High	0.55	Medium
762	Very High	Very High	Very High	Very High	0.55	Medium
763	Very High	Very High	Very High	Very High	0.55	Medium
764	Very High	Very High	Very High	Very High	0.55	Medium
765	Very High	Very High	Very High	Very High	0.55	Medium
766	Very High	Very High	Very High	Very High	0.55	Medium
767	Very High	Very High	Very High	Very High	0.55	Medium
768	Very High	Very High	Very High	Very High	0.55	Medium
769	Very High	Very High	Very High	Very High	0.55	Medium
770	Very High	Very High	Very High	Very High	0.55	Medium
771	Very High	Very High	Very High	Very High	0.55	Medium
772	Very High	Very High	Very High	Very High	0.45	Medium
773	Very High	Very High	Very High	Very High	0.45	Medium
774	Very High	Very High	Very High	Very High	0.45	Medium
775	Very High	Very High	Very High	Very High	0.45	Medium
776	Very High	Very High	Very High	Very High	0.45	Medium
777	Very High	Very High	Very High	Very High	0.45	Medium
778	Very High	Very High	Very High	Very High	0.45	Medium

779	Very High	Very High	Very High	Very High	0.45	Medium
780	Very High	Very High	Very High	Very High	0.45	Medium
781	Very High	Very High	Very High	Very High	0.45	Medium
782	Very High	Very High	Very High	Very High	0.45	Medium
783	Very High	Very High	Very High	Very High	0.45	Medium
784	Very High	Very High	Very High	Very High	0.45	Medium
785	Very High	Very High	Very High	Very High	0.45	Medium
786	Very High	Very High	Very High	Very High	0.45	Medium
787	Very High	Very High	Very High	Very High	0.45	Medium
788	Very High	Very High	Very High	Very High	0.36	Medium
789	Very High	Very High	Very High	Very High	0.36	Medium
790	Very High	Very High	Very High	Very High	0.36	Medium
791	Very High	Very High	Very High	Very High	0.36	Medium
792	Very High	Very High	Very High	Very High	0.36	Medium
793	Very High	Very High	Very High	Very High	0.36	Medium
794	Very High	Very High	Very High	Very High	0.36	Medium
795	Very High	Very High	Very High	Very High	0.36	Medium
796	Very High	Very High	Very High	Very High	0.36	Medium
797	Very High	Very High	Very High	Very High	0.36	Medium
798	Very High	Very High	Very High	Very High	0.36	Medium
799	Very High	Very High	Very High	Very High	0.36	Medium
800	Very High	Very High	Very High	Very High	0.36	Medium
801	Very High	Very High	Very High	Very High	0.36	Medium
802	Very High	Very High	Very High	Very High	0.36	Medium
803	Very High	Very High	Very High	Very High	0.36	Medium
804	Very High	Very High	Very High	Very High	0.64	Medium
805	Very High	Very High	Very High	Very High	0.64	Medium
806	Very High	Very High	Very High	Very High	0.64	Medium
807	Very High	Very High	Very High	Very High	0.64	Medium
808	Very High	Very High	Very High	Very High	0.64	Medium
809	Very High	Very High	Very High	Very High	0.64	Medium
810	Very High	Very High	Very High	Very High	0.64	Medium
811	Very High	Very High	Very High	Very High	0.64	Medium
812	Very High	Very High	Very High	Very High	0.64	Medium
813	Very High	Very High	Very High	Very High	0.64	Medium
814	Very High	Very High	Very High	Very High	0.64	Medium
815	Very High	Very High	Very High	Very High	0.64	Medium
816	Very High	Very High	Very High	Very High	0.64	Medium
817	Very High	Very High	Very High	Very High	0.64	Medium
818	Very High	Very High	Very High	Very High	0.64	Medium
819	Very High	Very High	Very High	Very High	0.64	Medium
820	Very High	Very High	Very High	Very High	0.55	Medium
821	Very High	Very High	Very High	Very High	0.55	Medium
822	Very High	Very High	Very High	Very High	0.55	Medium
823	Very High	Very High	Very High	Very High	0.55	Medium
824	Very High	Very High	Very High	Very High	0.55	Medium
825	Very High	Very High	Very High	Very High	0.55	Medium
826	Very High	Very High	Very High	Very High	0.55	Medium
827	Very High	Very High	Very High	Very High	0.55	Medium

828	Very High	Very High	Very High	Very High	0.55	Medium
829	Very High	Very High	Very High	Very High	0.55	Medium
830	Very High	Very High	Very High	Very High	0.55	Medium
831	Very High	Very High	Very High	Very High	0.55	Medium
832	Very High	Very High	Very High	Very High	0.55	Medium
833	Very High	Very High	Very High	Very High	0.55	Medium
834	Very High	Very High	Very High	Very High	0.55	Medium
835	Very High	Very High	Very High	Very High	0.55	Medium
836	Very High	Very High	Very High	Very High	0.45	Medium
837	Very High	Very High	Very High	Very High	0.45	Medium
838	Very High	Very High	Very High	Very High	0.45	Medium
839	Very High	Very High	Very High	Very High	0.45	Medium
840	Very High	Very High	Very High	Very High	0.45	Medium
841	Very High	Very High	Very High	Very High	0.45	Medium
842	Very High	Very High	Very High	Very High	0.45	Medium
843	Very High	Very High	Very High	Very High	0.45	Medium
844	Very High	Very High	Very High	Very High	0.45	Medium
845	Very High	Very High	Very High	Very High	0.45	Medium
846	Very High	Very High	Very High	Very High	0.45	Medium
847	Very High	Very High	Very High	Very High	0.45	Medium
848	Very High	Very High	Very High	Very High	0.45	Medium
849	Very High	Very High	Very High	Very High	0.45	Medium
850	Very High	Very High	Very High	Very High	0.45	Medium
851	Very High	Very High	Very High	Very High	0.45	Medium
852	Very High	Very High	Very High	Very High	0.18	Medium
853	Very High	Very High	Very High	Very High	0.18	Medium
854	Very High	Very High	Very High	Very High	0.18	Medium
855	Very High	Very High	Very High	Very High	0.18	Medium
856	Very High	Very High	Very High	Very High	0.18	Medium
857	Very High	Very High	Very High	Very High	0.18	Medium
858	Very High	Very High	Very High	Very High	0.18	Medium
859	Very High	Very High	Very High	Very High	0.18	Medium
860	Very High	Very High	Very High	Very High	0.18	Medium
861	Very High	Very High	Very High	Very High	0.18	Medium
862	Very High	Very High	Very High	Very High	0.18	Medium
863	Very High	Very High	Very High	Very High	0.18	Medium
864	Very High	Very High	Very High	Very High	0.18	Medium
865	Very High	Very High	Very High	Very High	0.18	Medium
866	Very High	Very High	Very High	Very High	0.18	Medium
867	Very High	Very High	Very High	Very High	0.18	Medium
868	Very High	Very High	Very High	Very High	0.18	Medium
869	Very High	Very High	Very High	Very High	0.18	Medium
870	Very High	Very High	Very High	Very High	0.18	Medium
871	Very High	Very High	Very High	Very High	0.18	Medium
872	Very High	Very High	Very High	Very High	0.18	Medium
873	Very High	Very High	Very High	Very High	0.18	Medium
874	Very High	Very High	Very High	Very High	0.18	Medium
875	Very High	Very High	Very High	Very High	0.18	Medium
876	Very High	Very High	Very High	Very High	0.18	Medium

877	Very High	Very High	Very High	Very High	0.18	Medium
878	Very High	Very High	Very High	Very High	0.18	Medium
879	Very High	Very High	Very High	Very High	0.18	Medium
880	Very High	Very High	Very High	Very High	0.18	Medium
881	Very High	Very High	Very High	Very High	0.18	Medium
882	Very High	Very High	Very High	Very High	0.18	Medium
883	Very High	Very High	Very High	Very High	0.18	Medium
884	Very High	Very High	Very High	Very High	0.18	Medium
885	Very High	Very High	Very High	Very High	0.18	Medium
886	Very High	Very High	Very High	Very High	0.18	Medium
887	Very High	Very High	Very High	Very High	0.18	Medium
888	Very High	Very High	Very High	Very High	0.18	Medium
889	Very High	Very High	Very High	Very High	0.18	Medium
890	Very High	Very High	Very High	Very High	0.18	Medium
891	Very High	Very High	Very High	Very High	0.18	Medium
892	Very High	Very High	Very High	Very High	0.18	Medium
893	Very High	Very High	Very High	Very High	0.18	Medium
894	Very High	Very High	Very High	Very High	0.18	Medium
895	Very High	Very High	Very High	Very High	0.18	Medium
896	Very High	Very High	Very High	Very High	0.18	Medium
897	Very High	Very High	Very High	Very High	0.18	Medium
898	Very High	Very High	Very High	Very High	0.18	Medium
899	Very High	Very High	Very High	Very High	0.18	Medium
900	Very High	Very High	Very High	Very High	0.18	Medium
901	Very High	Very High	Very High	Very High	0.18	Medium
902	Very High	Very High	Very High	Very High	0.18	Medium
903	Very High	Very High	Very High	Very High	0.18	Medium
904	Very High	Very High	Very High	Very High	0.18	Medium
905	Very High	Very High	Very High	Very High	0.18	Medium
906	Very High	Very High	Very High	Very High	0.18	Medium
907	Very High	Very High	Very High	Very High	0.18	Medium
908	Very High	Very High	Very High	Very High	0.18	Medium
909	Very High	Very High	Very High	Very High	0.18	Medium
910	Very High	Very High	Very High	Very High	0.18	Medium
911	Very High	Very High	Very High	Very High	0.18	Medium
912	Very High	Very High	Very High	Very High	0.18	Medium
913	Very High	Very High	Very High	Very High	0.18	Medium
914	Very High	Very High	Very High	Very High	0.18	Medium
915	Very High	Very High	Very High	Very High	0.18	Medium
916	Very High	Very High	Very High	Very High	0.37	Medium
917	Very High	Very High	Very High	Very High	0.37	Medium
918	Very High	Very High	Very High	Very High	0.37	Medium
919	Very High	Very High	Very High	Very High	0.37	Medium
920	Very High	Very High	Very High	Very High	0.37	Medium
921	Very High	Very High	Very High	Very High	0.37	Medium
922	Very High	Very High	Very High	Very High	0.37	Medium
923	Very High	Very High	Very High	Very High	0.37	Medium
924	Very High	Very High	Very High	Very High	0.37	Medium
925	Very High	Very High	Very High	Very High	0.37	Medium

926	Very High	Very High	Very High	Very High	0.37	Medium
927	Very High	Very High	Very High	Very High	0.37	Medium
928	Very High	Very High	Very High	Very High	0.37	Medium
929	Very High	Very High	Very High	Very High	0.37	Medium
930	Very High	Very High	Very High	Very High	0.37	Medium
931	Very High	Very High	Very High	Very High	0.37	Medium
932	Very High	Very High	Very High	Very High	0.37	Medium
933	Very High	Very High	Very High	Very High	0.37	Medium
934	Very High	Very High	Very High	Very High	0.37	Medium
935	Very High	Very High	Very High	Very High	0.37	Medium
936	Very High	Very High	Very High	Very High	0.37	Medium
937	Very High	Very High	Very High	Very High	0.37	Medium
938	Very High	Very High	Very High	Very High	0.37	Medium
939	Very High	Very High	Very High	Very High	0.37	Medium
940	Very High	Very High	Very High	Very High	0.37	Medium
941	Very High	Very High	Very High	Very High	0.37	Medium
942	Very High	Very High	Very High	Very High	0.37	Medium
943	Very High	Very High	Very High	Very High	0.37	Medium
944	Very High	Very High	Very High	Very High	0.37	Medium
945	Very High	Very High	Very High	Very High	0.37	Medium
946	Very High	Very High	Very High	Very High	0.37	Medium
947	Very High	Very High	Very High	Very High	0.37	Medium
948	Very High	Very High	Very High	Very High	0.37	Medium
949	Very High	Very High	Very High	Very High	0.37	Medium
950	Very High	Very High	Very High	Very High	0.37	Medium
951	Very High	Very High	Very High	Very High	0.37	Medium
952	Very High	Very High	Very High	Very High	0.37	Medium
953	Very High	Very High	Very High	Very High	0.37	Medium
954	Very High	Very High	Very High	Very High	0.37	Medium
955	Very High	Very High	Very High	Very High	0.37	Medium
956	Very High	Very High	Very High	Very High	0.37	Medium
957	Very High	Very High	Very High	Very High	0.37	Medium
958	Very High	Very High	Very High	Very High	0.37	Medium
959	Very High	Very High	Very High	Very High	0.37	Medium
960	Very High	Very High	Very High	Very High	0.37	Medium
961	Very High	Very High	Very High	Very High	0.37	Medium
962	Very High	Very High	Very High	Very High	0.37	Medium
963	Very High	Very High	Very High	Very High	0.37	Medium
964	Very High	Very High	Very High	Very High	0.37	Medium
965	Very High	Very High	Very High	Very High	0.37	Medium
966	Very High	Very High	Very High	Very High	0.37	Medium
967	Very High	Very High	Very High	Very High	0.37	Medium
968	Very High	Very High	Very High	Very High	0.37	Medium
969	Very High	Very High	Very High	Very High	0.37	Medium
970	Very High	Very High	Very High	Very High	0.37	Medium
971	Very High	Very High	Very High	Very High	0.37	Medium
972	Very High	Very High	Very High	Very High	0.37	Medium
973	Very High	Very High	Very High	Very High	0.37	Medium
974	Very High	Very High	Very High	Very High	0.37	Medium

975	Very High	Very High	Very High	Very High	0.37	Medium
976	Very High	Very High	Very High	Very High	0.37	Medium
977	Very High	Very High	Very High	Very High	0.37	Medium
978	Very High	Very High	Very High	Very High	0.37	Medium
979	Very High	Very High	Very High	Very High	0.37	Medium
980	Very High	Very High	Very High	Very High	0.27	Medium
981	Very High	Very High	Very High	Very High	0.27	Medium
982	Very High	Very High	Very High	Very High	0.27	Medium
983	Very High	Very High	Very High	Very High	0.27	Medium
984	Very High	Very High	Very High	Very High	0.27	Medium
985	Very High	Very High	Very High	Very High	0.27	Medium
986	Very High	Very High	Very High	Very High	0.27	Medium
987	Very High	Very High	Very High	Very High	0.27	Medium
988	Very High	Very High	Very High	Very High	0.27	Medium
989	Very High	Very High	Very High	Very High	0.27	Medium
990	Very High	Very High	Very High	Very High	0.27	Medium
991	Very High	Very High	Very High	Very High	0.27	Medium
992	Very High	Very High	Very High	Very High	0.27	Medium
993	Very High	Very High	Very High	Very High	0.27	Medium
994	Very High	Very High	Very High	Very High	0.27	Medium
995	Very High	Very High	Very High	Very High	0.27	Medium
996	Very High	Very High	Very High	Very High	0.27	Medium
997	Very High	Very High	Very High	Very High	0.27	Medium
998	Very High	Very High	Very High	Very High	0.27	Medium
999	Very High	Very High	Very High	Very High	0.27	Medium
1000	Very High	Very High	Very High	Very High	0.27	Medium
1001	Very High	Very High	Very High	Very High	0.27	Medium
1002	Very High	Very High	Very High	Very High	0.27	Medium
1003	Very High	Very High	Very High	Very High	0.27	Medium
1004	Very High	Very High	Very High	Very High	0.27	Medium
1005	Very High	Very High	Very High	Very High	0.27	Medium
1006	Very High	Very High	Very High	Very High	0.27	Medium
1007	Very High	Very High	Very High	Very High	0.27	Medium
1008	Very High	Very High	Very High	Very High	0.27	Medium
1009	Very High	Very High	Very High	Very High	0.27	Medium
1010	Very High	Very High	Very High	Very High	0.27	Medium
1011	Very High	Very High	Very High	Very High	0.27	Medium
1012	Very High	Very High	Very High	Very High	0.27	Medium
1013	Very High	Very High	Very High	Very High	0.27	Medium
1014	Very High	Very High	Very High	Very High	0.27	Medium
1015	Very High	Very High	Very High	Very High	0.27	Medium
1016	Very High	Very High	Very High	Very High	0.27	Medium
1017	Very High	Very High	Very High	Very High	0.27	Medium
1018	Very High	Very High	Very High	Very High	0.27	Medium
1019	Very High	Very High	Very High	Very High	0.27	Medium
1020	Very High	Very High	Very High	Very High	0.27	Medium
1021	Very High	Very High	Very High	Very High	0.27	Medium
1022	Very High	Very High	Very High	Very High	0.27	Medium
1023	Very High	Very High	Very High	Very High	0.27	Medium

1024	Very High	Very High	Very High	Very High	0.27	Medium
1025	Very High	Very High	Very High	Very High	0.27	Medium
1026	Very High	Very High	Very High	Very High	0.27	Medium
1027	Very High	Very High	Very High	Very High	0.27	Medium
1028	Very High	Very High	Very High	Very High	0.27	Medium
1029	Very High	Very High	Very High	Very High	0.27	Medium
1030	Very High	Very High	Very High	Very High	0.27	Medium
1031	Very High	Very High	Very High	Very High	0.27	Medium
1032	Very High	Very High	Very High	Very High	0.27	Medium
1033	Very High	Very High	Very High	Very High	0.27	Medium
1034	Very High	Very High	Very High	Very High	0.27	Medium
1035	Very High	Very High	Very High	Very High	0.27	Medium
1036	Very High	Very High	Very High	Very High	0.27	Medium
1037	Very High	Very High	Very High	Very High	0.27	Medium
1038	Very High	Very High	Very High	Very High	0.27	Medium
1039	Very High	Very High	Very High	Very High	0.27	Medium
1040	Very High	Very High	Very High	Very High	0.27	Medium
1041	Very High	Very High	Very High	Very High	0.27	Medium
1042	Very High	Very High	Very High	Very High	0.27	Medium
1043	Very High	Very High	Very High	Very High	0.27	Medium
1044	Very High	Very High	Very High	Very High	0.18	Medium
1045	Very High	Very High	Very High	Very High	0.18	Medium
1046	Very High	Very High	Very High	Very High	0.18	Medium
1047	Very High	Very High	Very High	Very High	0.18	Medium
1048	Very High	Very High	Very High	Very High	0.18	Medium
1049	Very High	Very High	Very High	Very High	0.18	Medium
1050	Very High	Very High	Very High	Very High	0.18	Medium
1051	Very High	Very High	Very High	Very High	0.18	Medium
1052	Very High	Very High	Very High	Very High	0.18	Medium
1053	Very High	Very High	Very High	Very High	0.18	Medium
1054	Very High	Very High	Very High	Very High	0.18	Medium
1055	Very High	Very High	Very High	Very High	0.18	Medium
1056	Very High	Very High	Very High	Very High	0.18	Medium
1057	Very High	Very High	Very High	Very High	0.18	Medium
1058	Very High	Very High	Very High	Very High	0.18	Medium
1059	Very High	Very High	Very High	Very High	0.18	Medium
1060	Very High	Very High	Very High	Very High	0.18	Medium
1061	Very High	Very High	Very High	Very High	0.18	Medium
1062	Very High	Very High	Very High	Very High	0.18	Medium
1063	Very High	Very High	Very High	Very High	0.18	Medium
1064	Very High	Very High	Very High	Very High	0.18	Medium
1065	Very High	Very High	Very High	Very High	0.18	Medium
1066	Very High	Very High	Very High	Very High	0.18	Medium
1067	Very High	Very High	Very High	Very High	0.18	Medium
1068	Very High	Very High	Very High	Very High	0.18	Medium
1069	Very High	Very High	Very High	Very High	0.18	Medium
1070	Very High	Very High	Very High	Very High	0.18	Medium
1071	Very High	Very High	Very High	Very High	0.18	Medium
1072	Very High	Very High	Very High	Very High	0.18	Medium

1073	Very High	Very High	Very High	Very High	0.18	Medium
1074	Very High	Very High	Very High	Very High	0.18	Medium
1075	Very High	Very High	Very High	Very High	0.18	Medium
1076	Very High	Very High	Very High	Very High	0.18	Medium
1077	Very High	Very High	Very High	Very High	0.18	Medium
1078	Very High	Very High	Very High	Very High	0.18	Medium
1079	Very High	Very High	Very High	Very High	0.18	Medium
1080	Very High	Very High	Very High	Very High	0.18	Medium
1081	Very High	Very High	Very High	Very High	0.18	Medium
1082	Very High	Very High	Very High	Very High	0.18	Medium
1083	Very High	Very High	Very High	Very High	0.18	Medium
1084	Very High	Very High	Very High	Very High	0.18	Medium
1085	Very High	Very High	Very High	Very High	0.18	Medium
1086	Very High	Very High	Very High	Very High	0.18	Medium
1087	Very High	Very High	Very High	Very High	0.18	Medium
1088	Very High	Very High	Very High	Very High	0.18	Medium
1089	Very High	Very High	Very High	Very High	0.18	Medium
1090	Very High	Very High	Very High	Very High	0.18	Medium
1091	Very High	Very High	Very High	Very High	0.18	Medium
1092	Very High	Very High	Very High	Very High	0.18	Medium
1093	Very High	Very High	Very High	Very High	0.18	Medium
1094	Very High	Very High	Very High	Very High	0.18	Medium
1095	Very High	Very High	Very High	Very High	0.18	Medium
1096	Very High	Very High	Very High	Very High	0.18	Medium
1097	Very High	Very High	Very High	Very High	0.18	Medium
1098	Very High	Very High	Very High	Very High	0.18	Medium
1099	Very High	Very High	Very High	Very High	0.18	Medium
1100	Very High	Very High	Very High	Very High	0.18	Medium
1101	Very High	Very High	Very High	Very High	0.18	Medium
1102	Very High	Very High	Very High	Very High	0.18	Medium
1103	Very High	Very High	Very High	Very High	0.18	Medium
1104	Very High	Very High	Very High	Very High	0.18	Medium
1105	Very High	Very High	Very High	Very High	0.18	Medium
1106	Very High	Very High	Very High	Very High	0.18	Medium
1107	Very High	Very High	Very High	Very High	0.18	Medium
1108	Very High	Very High	Very High	Very High	1.00	Low
1109	Very High	Very High	Very High	Very High	0.82	Low
1110	Very High	Very High	Very High	Very High	0.82	Low
1111	Very High	Very High	Very High	Very High	0.82	Low
1112	Very High	Very High	Very High	Very High	0.82	Low
1113	Very High	Very High	Very High	Very High	0.73	Low
1114	Very High	Very High	Very High	Very High	0.73	Low
1115	Very High	Very High	Very High	Very High	0.73	Low
1116	Very High	Very High	Very High	Very High	0.73	Low
1117	Very High	Very High	Very High	Very High	0.82	Low
1118	Very High	Very High	Very High	Very High	0.82	Low
1119	Very High	Very High	Very High	Very High	0.82	Low
1120	Very High	Very High	Very High	Very High	0.82	Low
1121	Very High	Very High	Very High	Very High	0.63	Low

1122	Very High	Very High	Very High	Very High	0.63	Low
1123	Very High	Very High	Very High	Very High	0.63	Low
1124	Very High	Very High	Very High	Very High	0.63	Low
1125	Very High	Very High	Very High	Very High	0.55	Low
1126	Very High	Very High	Very High	Very High	0.55	Low
1127	Very High	Very High	Very High	Very High	0.55	Low
1128	Very High	Very High	Very High	Very High	0.55	Low
1129	Very High	Very High	Very High	Very High	0.55	Low
1130	Very High	Very High	Very High	Very High	0.55	Low
1131	Very High	Very High	Very High	Very High	0.55	Low
1132	Very High	Very High	Very High	Very High	0.55	Low
1133	Very High	Very High	Very High	Very High	0.55	Low
1134	Very High	Very High	Very High	Very High	0.55	Low
1135	Very High	Very High	Very High	Very High	0.55	Low
1136	Very High	Very High	Very High	Very High	0.55	Low
1137	Very High	Very High	Very High	Very High	0.55	Low
1138	Very High	Very High	Very High	Very High	0.55	Low
1139	Very High	Very High	Very High	Very High	0.55	Low
1140	Very High	Very High	Very High	Very High	0.55	Low
1141	Very High	Very High	Very High	Very High	0.45	Low
1142	Very High	Very High	Very High	Very High	0.45	Low
1143	Very High	Very High	Very High	Very High	0.45	Low
1144	Very High	Very High	Very High	Very High	0.45	Low
1145	Very High	Very High	Very High	Very High	0.45	Low
1146	Very High	Very High	Very High	Very High	0.45	Low
1147	Very High	Very High	Very High	Very High	0.45	Low
1148	Very High	Very High	Very High	Very High	0.45	Low
1149	Very High	Very High	Very High	Very High	0.45	Low
1150	Very High	Very High	Very High	Very High	0.45	Low
1151	Very High	Very High	Very High	Very High	0.45	Low
1152	Very High	Very High	Very High	Very High	0.45	Low
1153	Very High	Very High	Very High	Very High	0.45	Low
1154	Very High	Very High	Very High	Very High	0.45	Low
1155	Very High	Very High	Very High	Very High	0.45	Low
1156	Very High	Very High	Very High	Very High	0.45	Low
1157	Very High	Very High	Very High	Very High	0.36	Low
1158	Very High	Very High	Very High	Very High	0.36	Low
1159	Very High	Very High	Very High	Very High	0.36	Low
1160	Very High	Very High	Very High	Very High	0.36	Low
1161	Very High	Very High	Very High	Very High	0.36	Low
1162	Very High	Very High	Very High	Very High	0.36	Low
1163	Very High	Very High	Very High	Very High	0.36	Low
1164	Very High	Very High	Very High	Very High	0.36	Low
1165	Very High	Very High	Very High	Very High	0.36	Low
1166	Very High	Very High	Very High	Very High	0.36	Low
1167	Very High	Very High	Very High	Very High	0.36	Low
1168	Very High	Very High	Very High	Very High	0.36	Low
1169	Very High	Very High	Very High	Very High	0.36	Low
1170	Very High	Very High	Very High	Very High	0.36	Low

1171	Very High	Very High	Very High	Very High	0.36	Low
1172	Very High	Very High	Very High	Very High	0.36	Low
1173	Very High	Very High	Very High	Very High	0.64	Low
1174	Very High	Very High	Very High	Very High	0.64	Low
1175	Very High	Very High	Very High	Very High	0.64	Low
1176	Very High	Very High	Very High	Very High	0.64	Low
1177	Very High	Very High	Very High	Very High	0.64	Low
1178	Very High	Very High	Very High	Very High	0.64	Low
1179	Very High	Very High	Very High	Very High	0.64	Low
1180	Very High	Very High	Very High	Very High	0.64	Low
1181	Very High	Very High	Very High	Very High	0.64	Low
1182	Very High	Very High	Very High	Very High	0.64	Low
1183	Very High	Very High	Very High	Very High	0.64	Low
1184	Very High	Very High	Very High	Very High	0.64	Low
1185	Very High	Very High	Very High	Very High	0.64	Low
1186	Very High	Very High	Very High	Very High	0.64	Low
1187	Very High	Very High	Very High	Very High	0.64	Low
1188	Very High	Very High	Very High	Very High	0.64	Low
1189	Very High	Very High	Very High	Very High	0.55	Low
1190	Very High	Very High	Very High	Very High	0.55	Low
1191	Very High	Very High	Very High	Very High	0.55	Low
1192	Very High	Very High	Very High	Very High	0.55	Low
1193	Very High	Very High	Very High	Very High	0.55	Low
1194	Very High	Very High	Very High	Very High	0.55	Low
1195	Very High	Very High	Very High	Very High	0.55	Low
1196	Very High	Very High	Very High	Very High	0.55	Low
1197	Very High	Very High	Very High	Very High	0.55	Low
1198	Very High	Very High	Very High	Very High	0.55	Low
1199	Very High	Very High	Very High	Very High	0.55	Low
1200	Very High	Very High	Very High	Very High	0.55	Low
1201	Very High	Very High	Very High	Very High	0.55	Low
1202	Very High	Very High	Very High	Very High	0.55	Low
1203	Very High	Very High	Very High	Very High	0.55	Low
1204	Very High	Very High	Very High	Very High	0.55	Low
1205	Very High	Very High	Very High	Very High	0.45	Low
1206	Very High	Very High	Very High	Very High	0.45	Low
1207	Very High	Very High	Very High	Very High	0.45	Low
1208	Very High	Very High	Very High	Very High	0.45	Low
1209	Very High	Very High	Very High	Very High	0.45	Low
1210	Very High	Very High	Very High	Very High	0.45	Low
1211	Very High	Very High	Very High	Very High	0.45	Low
1212	Very High	Very High	Very High	Very High	0.45	Low
1213	Very High	Very High	Very High	Very High	0.45	Low
1214	Very High	Very High	Very High	Very High	0.45	Low
1215	Very High	Very High	Very High	Very High	0.45	Low
1216	Very High	Very High	Very High	Very High	0.45	Low
1217	Very High	Very High	Very High	Very High	0.45	Low
1218	Very High	Very High	Very High	Very High	0.45	Low
1219	Very High	Very High	Very High	Very High	0.45	Low

1220	Very High	Very High	Very High	Very High	0.45	Low
1221	Very High	Very High	Very High	Very High	0.18	Low
1222	Very High	Very High	Very High	Very High	0.18	Low
1223	Very High	Very High	Very High	Very High	0.18	Low
1224	Very High	Very High	Very High	Very High	0.18	Low
1225	Very High	Very High	Very High	Very High	0.18	Low
1226	Very High	Very High	Very High	Very High	0.18	Low
1227	Very High	Very High	Very High	Very High	0.18	Low
1228	Very High	Very High	Very High	Very High	0.18	Low
1229	Very High	Very High	Very High	Very High	0.18	Low
1230	Very High	Very High	Very High	Very High	0.18	Low
1231	Very High	Very High	Very High	Very High	0.18	Low
1232	Very High	Very High	Very High	Very High	0.18	Low
1233	Very High	Very High	Very High	Very High	0.18	Low
1234	Very High	Very High	Very High	Very High	0.18	Low
1235	Very High	Very High	Very High	Very High	0.18	Low
1236	Very High	Very High	Very High	Very High	0.18	Low
1237	Very High	Very High	Very High	Very High	0.18	Low
1238	Very High	Very High	Very High	Very High	0.18	Low
1239	Very High	Very High	Very High	Very High	0.18	Low
1240	Very High	Very High	Very High	Very High	0.18	Low
1241	Very High	Very High	Very High	Very High	0.18	Low
1242	Very High	Very High	Very High	Very High	0.18	Low
1243	Very High	Very High	Very High	Very High	0.18	Low
1244	Very High	Very High	Very High	Very High	0.18	Low
1245	Very High	Very High	Very High	Very High	0.18	Low
1246	Very High	Very High	Very High	Very High	0.18	Low
1247	Very High	Very High	Very High	Very High	0.18	Low
1248	Very High	Very High	Very High	Very High	0.18	Low
1249	Very High	Very High	Very High	Very High	0.18	Low
1250	Very High	Very High	Very High	Very High	0.18	Low
1251	Very High	Very High	Very High	Very High	0.18	Low
1252	Very High	Very High	Very High	Very High	0.18	Low
1253	Very High	Very High	Very High	Very High	0.18	Low
1254	Very High	Very High	Very High	Very High	0.18	Low
1255	Very High	Very High	Very High	Very High	0.18	Low
1256	Very High	Very High	Very High	Very High	0.18	Low
1257	Very High	Very High	Very High	Very High	0.18	Low
1258	Very High	Very High	Very High	Very High	0.18	Low
1259	Very High	Very High	Very High	Very High	0.18	Low
1260	Very High	Very High	Very High	Very High	0.18	Low
1261	Very High	Very High	Very High	Very High	0.18	Low
1262	Very High	Very High	Very High	Very High	0.18	Low
1263	Very High	Very High	Very High	Very High	0.18	Low
1264	Very High	Very High	Very High	Very High	0.18	Low
1265	Very High	Very High	Very High	Very High	0.18	Low
1266	Very High	Very High	Very High	Very High	0.18	Low
1267	Very High	Very High	Very High	Very High	0.18	Low
1268	Very High	Very High	Very High	Very High	0.18	Low

1269	Very High	Very High	Very High	Very High	0.18	Low
1270	Very High	Very High	Very High	Very High	0.18	Low
1271	Very High	Very High	Very High	Very High	0.18	Low
1272	Very High	Very High	Very High	Very High	0.18	Low
1273	Very High	Very High	Very High	Very High	0.18	Low
1274	Very High	Very High	Very High	Very High	0.18	Low
1275	Very High	Very High	Very High	Very High	0.18	Low
1276	Very High	Very High	Very High	Very High	0.18	Low
1277	Very High	Very High	Very High	Very High	0.18	Low
1278	Very High	Very High	Very High	Very High	0.18	Low
1279	Very High	Very High	Very High	Very High	0.18	Low
1280	Very High	Very High	Very High	Very High	0.18	Low
1281	Very High	Very High	Very High	Very High	0.18	Low
1282	Very High	Very High	Very High	Very High	0.18	Low
1283	Very High	Very High	Very High	Very High	0.18	Low
1284	Very High	Very High	Very High	Very High	0.18	Low
1285	Very High	Very High	Very High	Very High	0.37	Low
1286	Very High	Very High	Very High	Very High	0.37	Low
1287	Very High	Very High	Very High	Very High	0.37	Low
1288	Very High	Very High	Very High	Very High	0.37	Low
1289	Very High	Very High	Very High	Very High	0.37	Low
1290	Very High	Very High	Very High	Very High	0.37	Low
1291	Very High	Very High	Very High	Very High	0.37	Low
1292	Very High	Very High	Very High	Very High	0.37	Low
1293	Very High	Very High	Very High	Very High	0.37	Low
1294	Very High	Very High	Very High	Very High	0.37	Low
1295	Very High	Very High	Very High	Very High	0.37	Low
1296	Very High	Very High	Very High	Very High	0.37	Low
1297	Very High	Very High	Very High	Very High	0.37	Low
1298	Very High	Very High	Very High	Very High	0.37	Low
1299	Very High	Very High	Very High	Very High	0.37	Low
1300	Very High	Very High	Very High	Very High	0.37	Low
1301	Very High	Very High	Very High	Very High	0.37	Low
1302	Very High	Very High	Very High	Very High	0.37	Low
1303	Very High	Very High	Very High	Very High	0.37	Low
1304	Very High	Very High	Very High	Very High	0.37	Low
1305	Very High	Very High	Very High	Very High	0.37	Low
1306	Very High	Very High	Very High	Very High	0.37	Low
1307	Very High	Very High	Very High	Very High	0.37	Low
1308	Very High	Very High	Very High	Very High	0.37	Low
1309	Very High	Very High	Very High	Very High	0.37	Low
1310	Very High	Very High	Very High	Very High	0.37	Low
1311	Very High	Very High	Very High	Very High	0.37	Low
1312	Very High	Very High	Very High	Very High	0.37	Low
1313	Very High	Very High	Very High	Very High	0.37	Low
1314	Very High	Very High	Very High	Very High	0.37	Low
1315	Very High	Very High	Very High	Very High	0.37	Low
1316	Very High	Very High	Very High	Very High	0.37	Low
1317	Very High	Very High	Very High	Very High	0.37	Low

1318	Very High	Very High	Very High	Very High	0.37	Low
1319	Very High	Very High	Very High	Very High	0.37	Low
1320	Very High	Very High	Very High	Very High	0.37	Low
1321	Very High	Very High	Very High	Very High	0.37	Low
1322	Very High	Very High	Very High	Very High	0.37	Low
1323	Very High	Very High	Very High	Very High	0.37	Low
1324	Very High	Very High	Very High	Very High	0.37	Low
1325	Very High	Very High	Very High	Very High	0.37	Low
1326	Very High	Very High	Very High	Very High	0.37	Low
1327	Very High	Very High	Very High	Very High	0.37	Low
1328	Very High	Very High	Very High	Very High	0.37	Low
1329	Very High	Very High	Very High	Very High	0.37	Low
1330	Very High	Very High	Very High	Very High	0.37	Low
1331	Very High	Very High	Very High	Very High	0.37	Low
1332	Very High	Very High	Very High	Very High	0.37	Low
1333	Very High	Very High	Very High	Very High	0.37	Low
1334	Very High	Very High	Very High	Very High	0.37	Low
1335	Very High	Very High	Very High	Very High	0.37	Low
1336	Very High	Very High	Very High	Very High	0.37	Low
1337	Very High	Very High	Very High	Very High	0.37	Low
1338	Very High	Very High	Very High	Very High	0.37	Low
1339	Very High	Very High	Very High	Very High	0.37	Low
1340	Very High	Very High	Very High	Very High	0.37	Low
1341	Very High	Very High	Very High	Very High	0.37	Low
1342	Very High	Very High	Very High	Very High	0.37	Low
1343	Very High	Very High	Very High	Very High	0.37	Low
1344	Very High	Very High	Very High	Very High	0.37	Low
1345	Very High	Very High	Very High	Very High	0.37	Low
1346	Very High	Very High	Very High	Very High	0.37	Low
1347	Very High	Very High	Very High	Very High	0.37	Low
1348	Very High	Very High	Very High	Very High	0.37	Low
1349	Very High	Very High	Very High	Very High	0.27	Low
1350	Very High	Very High	Very High	Very High	0.27	Low
1351	Very High	Very High	Very High	Very High	0.27	Low
1352	Very High	Very High	Very High	Very High	0.27	Low
1353	Very High	Very High	Very High	Very High	0.27	Low
1354	Very High	Very High	Very High	Very High	0.27	Low
1355	Very High	Very High	Very High	Very High	0.27	Low
1356	Very High	Very High	Very High	Very High	0.27	Low
1357	Very High	Very High	Very High	Very High	0.27	Low
1358	Very High	Very High	Very High	Very High	0.27	Low
1359	Very High	Very High	Very High	Very High	0.27	Low
1360	Very High	Very High	Very High	Very High	0.27	Low
1361	Very High	Very High	Very High	Very High	0.27	Low
1362	Very High	Very High	Very High	Very High	0.27	Low
1363	Very High	Very High	Very High	Very High	0.27	Low
1364	Very High	Very High	Very High	Very High	0.27	Low
1365	Very High	Very High	Very High	Very High	0.27	Low
1366	Very High	Very High	Very High	Very High	0.27	Low

1367	Very High	Very High	Very High	Very High	0.27	Low
1368	Very High	Very High	Very High	Very High	0.27	Low
1369	Very High	Very High	Very High	Very High	0.27	Low
1370	Very High	Very High	Very High	Very High	0.27	Low
1371	Very High	Very High	Very High	Very High	0.27	Low
1372	Very High	Very High	Very High	Very High	0.27	Low
1373	Very High	Very High	Very High	Very High	0.27	Low
1374	Very High	Very High	Very High	Very High	0.27	Low
1375	Very High	Very High	Very High	Very High	0.27	Low
1376	Very High	Very High	Very High	Very High	0.27	Low
1377	Very High	Very High	Very High	Very High	0.27	Low
1378	Very High	Very High	Very High	Very High	0.27	Low
1379	Very High	Very High	Very High	Very High	0.27	Low
1380	Very High	Very High	Very High	Very High	0.27	Low
1381	Very High	Very High	Very High	Very High	0.27	Low
1382	Very High	Very High	Very High	Very High	0.27	Low
1383	Very High	Very High	Very High	Very High	0.27	Low
1384	Very High	Very High	Very High	Very High	0.27	Low
1385	Very High	Very High	Very High	Very High	0.27	Low
1386	Very High	Very High	Very High	Very High	0.27	Low
1387	Very High	Very High	Very High	Very High	0.27	Low
1388	Very High	Very High	Very High	Very High	0.27	Low
1389	Very High	Very High	Very High	Very High	0.27	Low
1390	Very High	Very High	Very High	Very High	0.27	Low
1391	Very High	Very High	Very High	Very High	0.27	Low
1392	Very High	Very High	Very High	Very High	0.27	Low
1393	Very High	Very High	Very High	Very High	0.27	Low
1394	Very High	Very High	Very High	Very High	0.27	Low
1395	Very High	Very High	Very High	Very High	0.27	Low
1396	Very High	Very High	Very High	Very High	0.27	Low
1397	Very High	Very High	Very High	Very High	0.27	Low
1398	Very High	Very High	Very High	Very High	0.27	Low
1399	Very High	Very High	Very High	Very High	0.27	Low
1400	Very High	Very High	Very High	Very High	0.27	Low
1401	Very High	Very High	Very High	Very High	0.27	Low
1402	Very High	Very High	Very High	Very High	0.27	Low
1403	Very High	Very High	Very High	Very High	0.27	Low
1404	Very High	Very High	Very High	Very High	0.27	Low
1405	Very High	Very High	Very High	Very High	0.27	Low
1406	Very High	Very High	Very High	Very High	0.27	Low
1407	Very High	Very High	Very High	Very High	0.27	Low
1408	Very High	Very High	Very High	Very High	0.27	Low
1409	Very High	Very High	Very High	Very High	0.27	Low
1410	Very High	Very High	Very High	Very High	0.27	Low
1411	Very High	Very High	Very High	Very High	0.27	Low
1412	Very High	Very High	Very High	Very High	0.27	Low
1413	Very High	Very High	Very High	Very High	0.18	Low
1414	Very High	Very High	Very High	Very High	0.18	Low
1415	Very High	Very High	Very High	Very High	0.18	Low

1416	Very High	Very High	Very High	Very High	0.18	Low
1417	Very High	Very High	Very High	Very High	0.18	Low
1418	Very High	Very High	Very High	Very High	0.18	Low
1419	Very High	Very High	Very High	Very High	0.18	Low
1420	Very High	Very High	Very High	Very High	0.18	Low
1421	Very High	Very High	Very High	Very High	0.18	Low
1422	Very High	Very High	Very High	Very High	0.18	Low
1423	Very High	Very High	Very High	Very High	0.18	Low
1424	Very High	Very High	Very High	Very High	0.18	Low
1425	Very High	Very High	Very High	Very High	0.18	Low
1426	Very High	Very High	Very High	Very High	0.18	Low
1427	Very High	Very High	Very High	Very High	0.18	Low
1428	Very High	Very High	Very High	Very High	0.18	Low
1429	Very High	Very High	Very High	Very High	0.18	Low
1430	Very High	Very High	Very High	Very High	0.18	Low
1431	Very High	Very High	Very High	Very High	0.18	Low
1432	Very High	Very High	Very High	Very High	0.18	Low
1433	Very High	Very High	Very High	Very High	0.18	Low
1434	Very High	Very High	Very High	Very High	0.18	Low
1435	Very High	Very High	Very High	Very High	0.18	Low
1436	Very High	Very High	Very High	Very High	0.18	Low
1437	Very High	Very High	Very High	Very High	0.18	Low
1438	Very High	Very High	Very High	Very High	0.18	Low
1439	Very High	Very High	Very High	Very High	0.18	Low
1440	Very High	Very High	Very High	Very High	0.18	Low
1441	Very High	Very High	Very High	Very High	0.18	Low
1442	Very High	Very High	Very High	Very High	0.18	Low
1443	Very High	Very High	Very High	Very High	0.18	Low
1444	Very High	Very High	Very High	Very High	0.18	Low
1445	Very High	Very High	Very High	Very High	0.18	Low
1446	Very High	Very High	Very High	Very High	0.18	Low
1447	Very High	Very High	Very High	Very High	0.18	Low
1448	Very High	Very High	Very High	Very High	0.18	Low
1449	Very High	Very High	Very High	Very High	0.18	Low
1450	Very High	Very High	Very High	Very High	0.18	Low
1451	Very High	Very High	Very High	Very High	0.18	Low
1452	Very High	Very High	Very High	Very High	0.18	Low
1453	Very High	Very High	Very High	Very High	0.18	Low
1454	Very High	Very High	Very High	Very High	0.18	Low
1455	Very High	Very High	Very High	Very High	0.18	Low
1456	Very High	Very High	Very High	Very High	0.18	Low
1457	Very High	Very High	Very High	Very High	0.18	Low
1458	Very High	Very High	Very High	Very High	0.18	Low
1459	Very High	Very High	Very High	Very High	0.18	Low
1460	Very High	Very High	Very High	Very High	0.18	Low
1461	Very High	Very High	Very High	Very High	0.18	Low
1462	Very High	Very High	Very High	Very High	0.18	Low
1463	Very High	Very High	Very High	Very High	0.18	Low
1464	Very High	Very High	Very High	Very High	0.18	Low

1465	Very High	Very High	Very High	Very High	0.18	Low
1466	Very High	Very High	Very High	Very High	0.18	Low
1467	Very High	Very High	Very High	Very High	0.18	Low
1468	Very High	Very High	Very High	Very High	0.18	Low
1469	Very High	Very High	Very High	Very High	0.18	Low
1470	Very High	Very High	Very High	Very High	0.18	Low
1471	Very High	Very High	Very High	Very High	0.18	Low
1472	Very High	Very High	Very High	Very High	0.18	Low
1473	Very High	Very High	Very High	Very High	0.18	Low
1474	Very High	Very High	Very High	Very High	0.18	Low
1475	Very High	Very High	Very High	Very High	0.18	Low
1476	Very High	Very High	Very High	Very High	0.18	Low
1477	Very High	Very High	Very High	Very High	1.00	Very Low
1478	Very High	Very High	Very High	Very High	0.82	Very Low
1479	Very High	Very High	Very High	Very High	0.82	Very Low
1480	Very High	Very High	Very High	Very High	0.82	Very Low
1481	Very High	Very High	Very High	Very High	0.82	Very Low
1482	Very High	Very High	Very High	Very High	0.73	Very Low
1483	Very High	Very High	Very High	Very High	0.73	Very Low
1484	Very High	Very High	Very High	Very High	0.73	Very Low
1485	Very High	Very High	Very High	Very High	0.73	Very Low
1486	Very High	Very High	Very High	Very High	0.82	Very Low
1487	Very High	Very High	Very High	Very High	0.82	Very Low
1488	Very High	Very High	Very High	Very High	0.82	Very Low
1489	Very High	Very High	Very High	Very High	0.82	Very Low
1490	Very High	Very High	Very High	Very High	0.63	Very Low
1491	Very High	Very High	Very High	Very High	0.63	Very Low
1492	Very High	Very High	Very High	Very High	0.63	Very Low
1493	Very High	Very High	Very High	Very High	0.63	Very Low
1494	Very High	Very High	Very High	Very High	0.55	Very Low
1495	Very High	Very High	Very High	Very High	0.55	Very Low
1496	Very High	Very High	Very High	Very High	0.55	Very Low
1497	Very High	Very High	Very High	Very High	0.55	Very Low
1498	Very High	Very High	Very High	Very High	0.55	Very Low
1499	Very High	Very High	Very High	Very High	0.55	Very Low
1500	Very High	Very High	Very High	Very High	0.55	Very Low
1501	Very High	Very High	Very High	Very High	0.55	Very Low
1502	Very High	Very High	Very High	Very High	0.55	Very Low
1503	Very High	Very High	Very High	Very High	0.55	Very Low
1504	Very High	Very High	Very High	Very High	0.55	Very Low
1505	Very High	Very High	Very High	Very High	0.55	Very Low
1506	Very High	Very High	Very High	Very High	0.55	Very Low
1507	Very High	Very High	Very High	Very High	0.55	Very Low
1508	Very High	Very High	Very High	Very High	0.55	Very Low
1509	Very High	Very High	Very High	Very High	0.55	Very Low
1510	Very High	Very High	Very High	Very High	0.45	Very Low
1511	Very High	Very High	Very High	Very High	0.45	Very Low
1512	Very High	Very High	Very High	Very High	0.45	Very Low
1513	Very High	Very High	Very High	Very High	0.45	Very Low

1514	Very High	Very High	Very High	Very High	0.45	Very Low
1515	Very High	Very High	Very High	Very High	0.45	Very Low
1516	Very High	Very High	Very High	Very High	0.45	Very Low
1517	Very High	Very High	Very High	Very High	0.45	Very Low
1518	Very High	Very High	Very High	Very High	0.45	Very Low
1519	Very High	Very High	Very High	Very High	0.45	Very Low
1520	Very High	Very High	Very High	Very High	0.45	Very Low
1521	Very High	Very High	Very High	Very High	0.45	Very Low
1522	Very High	Very High	Very High	Very High	0.45	Very Low
1523	Very High	Very High	Very High	Very High	0.45	Very Low
1524	Very High	Very High	Very High	Very High	0.45	Very Low
1525	Very High	Very High	Very High	Very High	0.45	Very Low
1526	Very High	Very High	Very High	Very High	0.36	Very Low
1527	Very High	Very High	Very High	Very High	0.36	Very Low
1528	Very High	Very High	Very High	Very High	0.36	Very Low
1529	Very High	Very High	Very High	Very High	0.36	Very Low
1530	Very High	Very High	Very High	Very High	0.36	Very Low
1531	Very High	Very High	Very High	Very High	0.36	Very Low
1532	Very High	Very High	Very High	Very High	0.36	Very Low
1533	Very High	Very High	Very High	Very High	0.36	Very Low
1534	Very High	Very High	Very High	Very High	0.36	Very Low
1535	Very High	Very High	Very High	Very High	0.36	Very Low
1536	Very High	Very High	Very High	Very High	0.36	Very Low
1537	Very High	Very High	Very High	Very High	0.36	Very Low
1538	Very High	Very High	Very High	Very High	0.36	Very Low
1539	Very High	Very High	Very High	Very High	0.36	Very Low
1540	Very High	Very High	Very High	Very High	0.36	Very Low
1541	Very High	Very High	Very High	Very High	0.36	Very Low
1542	Very High	Very High	Very High	Very High	0.64	Very Low
1543	Very High	Very High	Very High	Very High	0.64	Very Low
1544	Very High	Very High	Very High	Very High	0.64	Very Low
1545	Very High	Very High	Very High	Very High	0.64	Very Low
1546	Very High	Very High	Very High	Very High	0.64	Very Low
1547	Very High	Very High	Very High	Very High	0.64	Very Low
1548	Very High	Very High	Very High	Very High	0.64	Very Low
1549	Very High	Very High	Very High	Very High	0.64	Very Low
1550	Very High	Very High	Very High	Very High	0.64	Very Low
1551	Very High	Very High	Very High	Very High	0.64	Very Low
1552	Very High	Very High	Very High	Very High	0.64	Very Low
1553	Very High	Very High	Very High	Very High	0.64	Very Low
1554	Very High	Very High	Very High	Very High	0.64	Very Low
1555	Very High	Very High	Very High	Very High	0.64	Very Low
1556	Very High	Very High	Very High	Very High	0.64	Very Low
1557	Very High	Very High	Very High	Very High	0.64	Very Low
1558	Very High	Very High	Very High	Very High	0.55	Very Low
1559	Very High	Very High	Very High	Very High	0.55	Very Low
1560	Very High	Very High	Very High	Very High	0.55	Very Low
1561	Very High	Very High	Very High	Very High	0.55	Very Low
1562	Very High	Very High	Very High	Very High	0.55	Very Low

1563	Very High	Very High	Very High	Very High	0.55	Very Low
1564	Very High	Very High	Very High	Very High	0.55	Very Low
1565	Very High	Very High	Very High	Very High	0.55	Very Low
1566	Very High	Very High	Very High	Very High	0.55	Very Low
1567	Very High	Very High	Very High	Very High	0.55	Very Low
1568	Very High	Very High	Very High	Very High	0.55	Very Low
1569	Very High	Very High	Very High	Very High	0.55	Very Low
1570	Very High	Very High	Very High	Very High	0.55	Very Low
1571	Very High	Very High	Very High	Very High	0.55	Very Low
1572	Very High	Very High	Very High	Very High	0.55	Very Low
1573	Very High	Very High	Very High	Very High	0.55	Very Low
1574	Very High	Very High	Very High	Very High	0.45	Very Low
1575	Very High	Very High	Very High	Very High	0.45	Very Low
1576	Very High	Very High	Very High	Very High	0.45	Very Low
1577	Very High	Very High	Very High	Very High	0.45	Very Low
1578	Very High	Very High	Very High	Very High	0.45	Very Low
1579	Very High	Very High	Very High	Very High	0.45	Very Low
1580	Very High	Very High	Very High	Very High	0.45	Very Low
1581	Very High	Very High	Very High	Very High	0.45	Very Low
1582	Very High	Very High	Very High	Very High	0.45	Very Low
1583	Very High	Very High	Very High	Very High	0.45	Very Low
1584	Very High	Very High	Very High	Very High	0.45	Very Low
1585	Very High	Very High	Very High	Very High	0.45	Very Low
1586	Very High	Very High	Very High	Very High	0.45	Very Low
1587	Very High	Very High	Very High	Very High	0.45	Very Low
1588	Very High	Very High	Very High	Very High	0.45	Very Low
1589	Very High	Very High	Very High	Very High	0.45	Very Low
1590	Very High	Very High	Very High	Very High	0.18	Very Low
1591	Very High	Very High	Very High	Very High	0.18	Very Low
1592	Very High	Very High	Very High	Very High	0.18	Very Low
1593	Very High	Very High	Very High	Very High	0.18	Very Low
1594	Very High	Very High	Very High	Very High	0.18	Very Low
1595	Very High	Very High	Very High	Very High	0.18	Very Low
1596	Very High	Very High	Very High	Very High	0.18	Very Low
1597	Very High	Very High	Very High	Very High	0.18	Very Low
1598	Very High	Very High	Very High	Very High	0.18	Very Low
1599	Very High	Very High	Very High	Very High	0.18	Very Low
1600	Very High	Very High	Very High	Very High	0.18	Very Low
1601	Very High	Very High	Very High	Very High	0.18	Very Low
1602	Very High	Very High	Very High	Very High	0.18	Very Low
1603	Very High	Very High	Very High	Very High	0.18	Very Low
1604	Very High	Very High	Very High	Very High	0.18	Very Low
1605	Very High	Very High	Very High	Very High	0.18	Very Low
1606	Very High	Very High	Very High	Very High	0.18	Very Low
1607	Very High	Very High	Very High	Very High	0.18	Very Low
1608	Very High	Very High	Very High	Very High	0.18	Very Low
1609	Very High	Very High	Very High	Very High	0.18	Very Low
1610	Very High	Very High	Very High	Very High	0.18	Very Low
1611	Very High	Very High	Very High	Very High	0.18	Very Low

1612	Very High	Very High	Very High	Very High	0.18	Very Low
1613	Very High	Very High	Very High	Very High	0.18	Very Low
1614	Very High	Very High	Very High	Very High	0.18	Very Low
1615	Very High	Very High	Very High	Very High	0.18	Very Low
1616	Very High	Very High	Very High	Very High	0.18	Very Low
1617	Very High	Very High	Very High	Very High	0.18	Very Low
1618	Very High	Very High	Very High	Very High	0.18	Very Low
1619	Very High	Very High	Very High	Very High	0.18	Very Low
1620	Very High	Very High	Very High	Very High	0.18	Very Low
1621	Very High	Very High	Very High	Very High	0.18	Very Low
1622	Very High	Very High	Very High	Very High	0.18	Very Low
1623	Very High	Very High	Very High	Very High	0.18	Very Low
1624	Very High	Very High	Very High	Very High	0.18	Very Low
1625	Very High	Very High	Very High	Very High	0.18	Very Low
1626	Very High	Very High	Very High	Very High	0.18	Very Low
1627	Very High	Very High	Very High	Very High	0.18	Very Low
1628	Very High	Very High	Very High	Very High	0.18	Very Low
1629	Very High	Very High	Very High	Very High	0.18	Very Low
1630	Very High	Very High	Very High	Very High	0.18	Very Low
1631	Very High	Very High	Very High	Very High	0.18	Very Low
1632	Very High	Very High	Very High	Very High	0.18	Very Low
1633	Very High	Very High	Very High	Very High	0.18	Very Low
1634	Very High	Very High	Very High	Very High	0.18	Very Low
1635	Very High	Very High	Very High	Very High	0.18	Very Low
1636	Very High	Very High	Very High	Very High	0.18	Very Low
1637	Very High	Very High	Very High	Very High	0.18	Very Low
1638	Very High	Very High	Very High	Very High	0.18	Very Low
1639	Very High	Very High	Very High	Very High	0.18	Very Low
1640	Very High	Very High	Very High	Very High	0.18	Very Low
1641	Very High	Very High	Very High	Very High	0.18	Very Low
1642	Very High	Very High	Very High	Very High	0.18	Very Low
1643	Very High	Very High	Very High	Very High	0.18	Very Low
1644	Very High	Very High	Very High	Very High	0.18	Very Low
1645	Very High	Very High	Very High	Very High	0.18	Very Low
1646	Very High	Very High	Very High	Very High	0.18	Very Low
1647	Very High	Very High	Very High	Very High	0.18	Very Low
1648	Very High	Very High	Very High	Very High	0.18	Very Low
1649	Very High	Very High	Very High	Very High	0.18	Very Low
1650	Very High	Very High	Very High	Very High	0.18	Very Low
1651	Very High	Very High	Very High	Very High	0.18	Very Low
1652	Very High	Very High	Very High	Very High	0.18	Very Low
1653	Very High	Very High	Very High	Very High	0.18	Very Low
1654	Very High	Very High	Very High	Very High	0.37	Very Low
1655	Very High	Very High	Very High	Very High	0.37	Very Low
1656	Very High	Very High	Very High	Very High	0.37	Very Low
1657	Very High	Very High	Very High	Very High	0.37	Very Low
1658	Very High	Very High	Very High	Very High	0.37	Very Low
1659	Very High	Very High	Very High	Very High	0.37	Very Low
1660	Very High	Very High	Very High	Very High	0.37	Very Low

1661	Very High	Very High	Very High	Very High	0.37	Very Low
1662	Very High	Very High	Very High	Very High	0.37	Very Low
1663	Very High	Very High	Very High	Very High	0.37	Very Low
1664	Very High	Very High	Very High	Very High	0.37	Very Low
1665	Very High	Very High	Very High	Very High	0.37	Very Low
1666	Very High	Very High	Very High	Very High	0.37	Very Low
1667	Very High	Very High	Very High	Very High	0.37	Very Low
1668	Very High	Very High	Very High	Very High	0.37	Very Low
1669	Very High	Very High	Very High	Very High	0.37	Very Low
1670	Very High	Very High	Very High	Very High	0.37	Very Low
1671	Very High	Very High	Very High	Very High	0.37	Very Low
1672	Very High	Very High	Very High	Very High	0.37	Very Low
1673	Very High	Very High	Very High	Very High	0.37	Very Low
1674	Very High	Very High	Very High	Very High	0.37	Very Low
1675	Very High	Very High	Very High	Very High	0.37	Very Low
1676	Very High	Very High	Very High	Very High	0.37	Very Low
1677	Very High	Very High	Very High	Very High	0.37	Very Low
1678	Very High	Very High	Very High	Very High	0.37	Very Low
1679	Very High	Very High	Very High	Very High	0.37	Very Low
1680	Very High	Very High	Very High	Very High	0.37	Very Low
1681	Very High	Very High	Very High	Very High	0.37	Very Low
1682	Very High	Very High	Very High	Very High	0.37	Very Low
1683	Very High	Very High	Very High	Very High	0.37	Very Low
1684	Very High	Very High	Very High	Very High	0.37	Very Low
1685	Very High	Very High	Very High	Very High	0.37	Very Low
1686	Very High	Very High	Very High	Very High	0.37	Very Low
1687	Very High	Very High	Very High	Very High	0.37	Very Low
1688	Very High	Very High	Very High	Very High	0.37	Very Low
1689	Very High	Very High	Very High	Very High	0.37	Very Low
1690	Very High	Very High	Very High	Very High	0.37	Very Low
1691	Very High	Very High	Very High	Very High	0.37	Very Low
1692	Very High	Very High	Very High	Very High	0.37	Very Low
1693	Very High	Very High	Very High	Very High	0.37	Very Low
1694	Very High	Very High	Very High	Very High	0.37	Very Low
1695	Very High	Very High	Very High	Very High	0.37	Very Low
1696	Very High	Very High	Very High	Very High	0.37	Very Low
1697	Very High	Very High	Very High	Very High	0.37	Very Low
1698	Very High	Very High	Very High	Very High	0.37	Very Low
1699	Very High	Very High	Very High	Very High	0.37	Very Low
1700	Very High	Very High	Very High	Very High	0.37	Very Low
1701	Very High	Very High	Very High	Very High	0.37	Very Low
1702	Very High	Very High	Very High	Very High	0.37	Very Low
1703	Very High	Very High	Very High	Very High	0.37	Very Low
1704	Very High	Very High	Very High	Very High	0.37	Very Low
1705	Very High	Very High	Very High	Very High	0.37	Very Low
1706	Very High	Very High	Very High	Very High	0.37	Very Low
1707	Very High	Very High	Very High	Very High	0.37	Very Low
1708	Very High	Very High	Very High	Very High	0.37	Very Low
1709	Very High	Very High	Very High	Very High	0.37	Very Low

1710	Very High	Very High	Very High	Very High	0.37	Very Low
1711	Very High	Very High	Very High	Very High	0.37	Very Low
1712	Very High	Very High	Very High	Very High	0.37	Very Low
1713	Very High	Very High	Very High	Very High	0.37	Very Low
1714	Very High	Very High	Very High	Very High	0.37	Very Low
1715	Very High	Very High	Very High	Very High	0.37	Very Low
1716	Very High	Very High	Very High	Very High	0.37	Very Low
1717	Very High	Very High	Very High	Very High	0.37	Very Low
1718	Very High	Very High	Very High	Very High	0.27	Very Low
1719	Very High	Very High	Very High	Very High	0.27	Very Low
1720	Very High	Very High	Very High	Very High	0.27	Very Low
1721	Very High	Very High	Very High	Very High	0.27	Very Low
1722	Very High	Very High	Very High	Very High	0.27	Very Low
1723	Very High	Very High	Very High	Very High	0.27	Very Low
1724	Very High	Very High	Very High	Very High	0.27	Very Low
1725	Very High	Very High	Very High	Very High	0.27	Very Low
1726	Very High	Very High	Very High	Very High	0.27	Very Low
1727	Very High	Very High	Very High	Very High	0.27	Very Low
1728	Very High	Very High	Very High	Very High	0.27	Very Low
1729	Very High	Very High	Very High	Very High	0.27	Very Low
1730	Very High	Very High	Very High	Very High	0.27	Very Low
1731	Very High	Very High	Very High	Very High	0.27	Very Low
1732	Very High	Very High	Very High	Very High	0.27	Very Low
1733	Very High	Very High	Very High	Very High	0.27	Very Low
1734	Very High	Very High	Very High	Very High	0.27	Very Low
1735	Very High	Very High	Very High	Very High	0.27	Very Low
1736	Very High	Very High	Very High	Very High	0.27	Very Low
1737	Very High	Very High	Very High	Very High	0.27	Very Low
1738	Very High	Very High	Very High	Very High	0.27	Very Low
1739	Very High	Very High	Very High	Very High	0.27	Very Low
1740	Very High	Very High	Very High	Very High	0.27	Very Low
1741	Very High	Very High	Very High	Very High	0.27	Very Low
1742	Very High	Very High	Very High	Very High	0.27	Very Low
1743	Very High	Very High	Very High	Very High	0.27	Very Low
1744	Very High	Very High	Very High	Very High	0.27	Very Low
1745	Very High	Very High	Very High	Very High	0.27	Very Low
1746	Very High	Very High	Very High	Very High	0.27	Very Low
1747	Very High	Very High	Very High	Very High	0.27	Very Low
1748	Very High	Very High	Very High	Very High	0.27	Very Low
1749	Very High	Very High	Very High	Very High	0.27	Very Low
1750	Very High	Very High	Very High	Very High	0.27	Very Low
1751	Very High	Very High	Very High	Very High	0.27	Very Low
1752	Very High	Very High	Very High	Very High	0.27	Very Low
1753	Very High	Very High	Very High	Very High	0.27	Very Low
1754	Very High	Very High	Very High	Very High	0.27	Very Low
1755	Very High	Very High	Very High	Very High	0.27	Very Low
1756	Very High	Very High	Very High	Very High	0.27	Very Low
1757	Very High	Very High	Very High	Very High	0.27	Very Low
1758	Very High	Very High	Very High	Very High	0.27	Very Low

1759	Very High	Very High	Very High	Very High	0.27	Very Low
1760	Very High	Very High	Very High	Very High	0.27	Very Low
1761	Very High	Very High	Very High	Very High	0.27	Very Low
1762	Very High	Very High	Very High	Very High	0.27	Very Low
1763	Very High	Very High	Very High	Very High	0.27	Very Low
1764	Very High	Very High	Very High	Very High	0.27	Very Low
1765	Very High	Very High	Very High	Very High	0.27	Very Low
1766	Very High	Very High	Very High	Very High	0.27	Very Low
1767	Very High	Very High	Very High	Very High	0.27	Very Low
1768	Very High	Very High	Very High	Very High	0.27	Very Low
1769	Very High	Very High	Very High	Very High	0.27	Very Low
1770	Very High	Very High	Very High	Very High	0.27	Very Low
1771	Very High	Very High	Very High	Very High	0.27	Very Low
1772	Very High	Very High	Very High	Very High	0.27	Very Low
1773	Very High	Very High	Very High	Very High	0.27	Very Low
1774	Very High	Very High	Very High	Very High	0.27	Very Low
1775	Very High	Very High	Very High	Very High	0.27	Very Low
1776	Very High	Very High	Very High	Very High	0.27	Very Low
1777	Very High	Very High	Very High	Very High	0.27	Very Low
1778	Very High	Very High	Very High	Very High	0.27	Very Low
1779	Very High	Very High	Very High	Very High	0.27	Very Low
1780	Very High	Very High	Very High	Very High	0.27	Very Low
1781	Very High	Very High	Very High	Very High	0.27	Very Low
1782	Very High	Very High	Very High	Very High	0.18	Very Low
1783	Very High	Very High	Very High	Very High	0.18	Very Low
1784	Very High	Very High	Very High	Very High	0.18	Very Low
1785	Very High	Very High	Very High	Very High	0.18	Very Low
1786	Very High	Very High	Very High	Very High	0.18	Very Low
1787	Very High	Very High	Very High	Very High	0.18	Very Low
1788	Very High	Very High	Very High	Very High	0.18	Very Low
1789	Very High	Very High	Very High	Very High	0.18	Very Low
1790	Very High	Very High	Very High	Very High	0.18	Very Low
1791	Very High	Very High	Very High	Very High	0.18	Very Low
1792	Very High	Very High	Very High	Very High	0.18	Very Low
1793	Very High	Very High	Very High	Very High	0.18	Very Low
1794	Very High	Very High	Very High	Very High	0.18	Very Low
1795	Very High	Very High	Very High	Very High	0.18	Very Low
1796	Very High	Very High	Very High	Very High	0.18	Very Low
1797	Very High	Very High	Very High	Very High	0.18	Very Low
1798	Very High	Very High	Very High	Very High	0.18	Very Low
1799	Very High	Very High	Very High	Very High	0.18	Very Low
1800	Very High	Very High	Very High	Very High	0.18	Very Low
1801	Very High	Very High	Very High	Very High	0.18	Very Low
1802	Very High	Very High	Very High	Very High	0.18	Very Low
1803	Very High	Very High	Very High	Very High	0.18	Very Low
1804	Very High	Very High	Very High	Very High	0.18	Very Low
1805	Very High	Very High	Very High	Very High	0.18	Very Low
1806	Very High	Very High	Very High	Very High	0.18	Very Low
1807	Very High	Very High	Very High	Very High	0.18	Very Low

1808	Very High	Very High	Very High	Very High	0.18	Very Low
1809	Very High	Very High	Very High	Very High	0.18	Very Low
1810	Very High	Very High	Very High	Very High	0.18	Very Low
1811	Very High	Very High	Very High	Very High	0.18	Very Low
1812	Very High	Very High	Very High	Very High	0.18	Very Low
1813	Very High	Very High	Very High	Very High	0.18	Very Low
1814	Very High	Very High	Very High	Very High	0.18	Very Low
1815	Very High	Very High	Very High	Very High	0.18	Very Low
1816	Very High	Very High	Very High	Very High	0.18	Very Low
1817	Very High	Very High	Very High	Very High	0.18	Very Low
1818	Very High	Very High	Very High	Very High	0.18	Very Low
1819	Very High	Very High	Very High	Very High	0.18	Very Low
1820	Very High	Very High	Very High	Very High	0.18	Very Low
1821	Very High	Very High	Very High	Very High	0.18	Very Low
1822	Very High	Very High	Very High	Very High	0.18	Very Low
1823	Very High	Very High	Very High	Very High	0.18	Very Low
1824	Very High	Very High	Very High	Very High	0.18	Very Low
1825	Very High	Very High	Very High	Very High	0.18	Very Low
1826	Very High	Very High	Very High	Very High	0.18	Very Low
1827	Very High	Very High	Very High	Very High	0.18	Very Low
1828	Very High	Very High	Very High	Very High	0.18	Very Low
1829	Very High	Very High	Very High	Very High	0.18	Very Low
1830	Very High	Very High	Very High	Very High	0.18	Very Low
1831	Very High	Very High	Very High	Very High	0.18	Very Low
1832	Very High	Very High	Very High	Very High	0.18	Very Low
1833	Very High	Very High	Very High	Very High	0.18	Very Low
1834	Very High	Very High	Very High	Very High	0.18	Very Low
1835	Very High	Very High	Very High	Very High	0.18	Very Low
1836	Very High	Very High	Very High	Very High	0.18	Very Low
1837	Very High	Very High	Very High	Very High	0.18	Very Low
1838	Very High	Very High	Very High	Very High	0.18	Very Low
1839	Very High	Very High	Very High	Very High	0.18	Very Low
1840	Very High	Very High	Very High	Very High	0.18	Very Low
1841	Very High	Very High	Very High	Very High	0.18	Very Low
1842	Very High	Very High	Very High	Very High	0.18	Very Low
1843	Very High	Very High	Very High	Very High	0.18	Very Low
1844	Very High	Very High	Very High	Very High	0.18	Very Low
1845	Very High	Very High	Very High	Very High	0.18	Very Low